EMERGING TECHNOLOGIES AND THEIR IMPACT
September/October 2006
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Technology Review

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Exclusive Photos from the Space Shuttle p30

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Special Issue

The TR35

The Young Innovators with This Year's Best Ideas

Page 43



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- **Sebastian Thrun**, Director, AI Laboratory, Stanford University; DARPA Grand Challenge Winner
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Sebastian Thrun, DARPA Grand Challenge Winner

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Contents

Volume 109, Number 4



Cover illustration by Jonathon Rosen

Features

43 **TR35: Young innovators with this year's best ideas**

Our annual selection of 35 innovators under the age of 35 (the awards began in 1999 as the TR100) is a celebration of the young scientists, computer programmers, and engineers inventing the future of technology. These are people who are radically changing their disciplines: a neurobiologist devising a way to make particular neurons fire at will; a chemist creating a new route to protein drugs; an electrical engineer building electronics that stretch like rubber bands; a neuroscientist deciphering the signals from the brain; a chemical engineer cleaning up toxic waste with nanoparticles. Two of the TR35 receive special awards: Joshua Schachter is the Innovator of the Year for his popularization of tagging on the Web; and Christina Galitsky is Humanitarian of the Year for her relentless efforts to bring useful technologies to some of the world's poorest communities.

4 **Contributors**

8 **Letters**

10 **From the Editor**

Forward

13 **An Eye on Everything**
A sphere of optical fibers could lead to clothing that "sees."

14 **Movies That Fight Back**
New technologies battle bootleggers.

15 **Smart Pages**
Xerox technology protects sensitive information.

15 **Ultrasonic Tourniquet**
Waves to stop battlefield bleeding

16 **The Rockets Are Coming**
A flurry of launches makes 2006 a big year for private spacecraft.

17 **Ethanol vs. Biodiesel**
Diesel from soybeans is the best bet.

17 **Seeing Music**
Software maps Chopin.

18 **India's Ten-Year Patent Drive**
The West begins licensing Indian-born inventions.

19 **A Safer Stent**
Device releases drugs carefully

20 **Carbon Ready**
Sequestration science is far ahead of needed policy.
And more ...

Hack

22 **The Hundred-Dollar Laptop**
Nicholas Negroponte's machine has a working prototype.
By Daniel Turner

Q&A

24 **Arthur Caplan**
Who elected *you* king?
By David Ewing Duncan

Notebooks

26 **The Future of Nanoelectronics**
New materials will complement, not compete with, silicon devices.
By Song Jin

26 **Development Powered by Education**
Interactive tools could train African students for the workplace.
By Matthew Herren

28 **Finding Evolution's Signatures**
Scientists can decipher hidden elements in the human genome.
By Manolis Kellis

Photo Essay

30 **NASA's New Cameras**
Discovery shuttle astronauts tested new technologies while orbiting 400 kilometers above Earth.
By Katherine Bourzac

Reviews

72 **The Art of the Possible**
Can Eric Bonabeau's new Hunch Engine expand your mind?
By Wade Roush

74 **Q Is for Quixotic**
Motorola decided its new Q phone should run Windows. Big mistake.
By Simson Garfinkel

76 **Golden Gate Lark**
Should San Franciscans trust Google and their mayor to improvise the city's Wi-Fi network?
By Mark Williams

Demo

78 **Peering into the Brain**
Watching live neurons in mice, Elly Nedivi has seen surprising growth.
By Emily Singer

From the Labs

82 **Information Technology**

84 **Nanotechnology**

86 **Biotechnology**

7 Years Ago in *TR*

88 **Where Are They Now?**
We got curious, so we checked in on three of the original TR100 winners.
By Jessica B. Baker



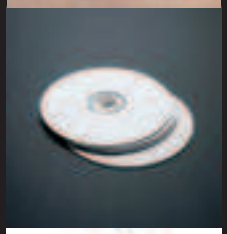
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Contributors



Horace Freeland Judson wrote the profile of Edward Boyden *(p. 52)*, who graduated from MIT with perfect grades at the age of 19, and who has created a protein that allows neuroscientists to find specific types of neurons and activate them on cue. "His ambitions are vaulting, his vision romantic," says Judson of Boyden, one of this year's TR35. "Yet he loves the practical application, loves devising inventions." Judson is the author of *The Eighth Day of Creation*, a history of molecular biology whose first three chapters appeared in the *New Yorker* in 1978. He has held academic appointments at Johns Hopkins and Stanford, and he founded George Washington University's Center for History of Recent Science. He recently signed contracts for two books: one will include a chapter expanding on an article on gene therapy to appear in an upcoming issue of this magazine; the other will expand on the article he wrote for this magazine on China and science *("The Great Chinese Experiment," December 2005/January 2006)*.



Jon Cohen wrote a brief profile of one of this year's TR35: Alice Ting *(p. 55)*, an assistant professor of chemistry at MIT, who has developed a way of observing the minute inner workings of a living cell. "Imagine," says Cohen, "seeing a movie of the neurons in the brain as they learn something new, à la *CSI* showing you the inside of an aorta as it bursts. It's such a fantastical idea that it sounds like something a Hollyweird screenwriter would cook up after drinking too many shots of cheap tequila. I heard it from Alice Ting whose lab can't do that yet, but give her time. She's only 31." Cohen, a correspondent for *Science* who has written for a number of other publications, specializes in reporting on biomedical research. He is the author of two books, *Shots in the Dark: The Wayward Search for an AIDS Vaccine* and *Coming to Term: Uncovering the Truth about Miscarriage*.



Douglas McGray wrote the profile of Christina Galitsky, our Humanitarian of the Year *(p. 60)*. Galitsky works at Lawrence Berkeley National Laboratory, where she advises companies on ways to save energy, but she has also taken on projects outside the scope of her job, such as an energy-efficient outdoor stove for refugees. "She's tackling some tough scientific challenges, but I appreciated that these aren't just intellectual puzzles for her," says McGray. "There's something simple and humane in the way she talks about science. She'll drop into technical lingo, but it's never long before she brings the conversation back to the people and communities who will benefit from her research—or live with science's failures." McGray is a San Francisco–based writer and a fellow at the New America Foundation. He has written for the *Atlantic Monthly*, the *New York Times Magazine*, *West*, and *Wired*.



Simson Garfinkel, in reviewing the new Q phone from Motorola, argues that users want software that understands the context in which they are operating and uses as simple an interface as possible *(see "Q Is for Quixotic," p. 74)*. "I was hoping that the Q would be a really amazing phone that I could use for my day-to-day activities, instead of the Treo 700p," he says. "The Treo is big and bulky and the Q is small and sleek, and I was really excited about it. The hardware is amazing, but I was worried about the fact that it was running Windows Mobile. Apparently I was right to be worried." Garfinkel is a postdoctoral fellow at the Center for Research on Computation and Society at Harvard University and a consulting scientist at Basis Technology, which develops software for extracting meaningful intelligence from unstructured text. He is also a founder of Sandstorm Enterprises, a computer security firm that develops advanced computer forensic tools used by businesses and governments to audit their systems. Garfinkel has published articles about information policy and terrorism since the late 1980s.



Jonathon Rosen illustrated this month's cover. "I'm a huge fan of engineering and technology," he says, "so I was completely thrilled to be invited to interpret the '35 under 35' idea for the magazine. I decided to mix biology (cells multiplying in an embryo) and cosmology—an orrery of the embryo as the center of a mechanical universe." Rosen's work is in the permanent collection of the Metropolitan Museum of Art in New York and has appeared in *Rolling Stone*, the *New York Times*, *World Art*, *I.D.*, *Eye*, and many other publications. He is also the author of the books *Intestinal Fortitude* and *The Birth of Machine Consciousness*. Rosen teaches the history of anatomy and medical illustration at the School of Visual Arts in New York.



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Letters

Our July/August 2006 issue centered on energy—as did most of the letters we received after publication.

The Nuclear Option

Matthew Wald did a great job reviewing the current state of nuclear power ("The Best Nuclear Option," July/August 2006). I know how complex the subject is; I spent 13 years in the naval nuclear-power program, 10 years working on spent-fuel recycling and production of breeder-reactor fuels, and 10 years consulting for the U.S. Departments of Energy and Defense.

Yes, nuclear power is an obvious choice for production of electricity as an alternative to fossil fuels. The required technology is available, as indicated by the more than 400 nuclear power plants operating in 31 countries. The next step in our country will be to recycle the spent-fuel discharges. The technology to do that is also available and is being used around the world.

Another step will be to use breeder reactors, in which more fuel is produced than charged. Breeders will be used to accommodate depletion of uranium ore and the need to mine it.

Bill Frankhouser
Elizabethtown, PA

A New Way to Get Ethanol Cheaply

In his article on the production of ethanol ("Redesigning Life to Make Ethanol," July/August 2006), Jamie Shreeve writes, "Processing ethanol from cellulose—wheat and rice straw, switchgrass, paper pulp, agricultural waste products like corn cobs and leaves—has the potential to squeeze at least twice as much fuel from the same area of land, because so much more biomass is available per acre."

Instead of using "waste products" to restore the fertility, improve the texture, and increase the water-retaining capacity of land, the policies advocated by Jamie Shreeve would degrade our land. You cannot "squeeze" land for long before it becomes infertile.

Irma Esrig Cohen
Ottawa, Ontario

Editor's Letter

In his July/August editor's letter, Jason Pontin writes that "it is now settled fact that our industries are changing the weather." His statement creates the impression that the MIT community is substantially in agreement with the belief that industrial emissions are "quickly and ruinously" changing the climate, with only the rate in doubt. But within the MIT community there is not unanimity in the fear of catastrophic climate change due to industrial emissions. I refer readers to a July 2 *Wall Street Journal* article titled "Don't Believe the Hype." The writer, Richard S. Lindzen, Alfred P. Sloan Professor of Meteorology at MIT, effectively demolishes the campaign to convince the public of scientific unanimity on the severe imminent danger of greenhouse-gas emissions.

Stanley Kasper
Pawleys Island, SC

Jason Pontin is right to advocate Pigovian fees, which are paid to governments for the use of scarce public resources (fish in the sea, the environment's tolerance for carbon dioxide, etc.). They enforce a constraint with a minimum of central planning.

Pontin briefly describes another remedy for pollution: capping emission limits, then allowing polluters to trade emission credits. He rightly says that such "cap and trade" schemes don't work very well. I'd like to add that they aren't fair and can amount to a land grab. For hundreds of years, common resources from acreage to radio bandwidth have been given away. Even if cap-and-trade does not encourage industrialists to pad their emissions now, it is unjust to give such property rights to polluters.

Jorgen Harmse
Austin, TX

Jason Pontin writes that "the rich world will *never* voluntarily accept any reduction in its accustomed manner of living, nor will the poor world surrender its legitimate aspirations to wealth." That's one way to look at it, but is it not possible that we will simply run out of certain resources if we don't use less of them? The slowly growing practice of "voluntary simplicity" attests to the fact that individuals can unilaterally decide to live simply and consume less.

Shahzeen Attari
Pittsburgh, PA

"Homo Conexus"

I read with interest James Fallows's piece on the new wave of Web-based applications sometimes called Web 2.0 ("Homo Conexus," July/August 2006). In using these new programs, he sometimes found that while a new online service was impressive, he was just too old to enjoy it. Unfortunately, I often feel quite the same way. I enjoy reading about exciting technological innovations, but—nose pressed to glass—cannot really participate.

I also liked Fallows's observation that trust, in general, is important to Web 2.0, but would like to add that Web 2.0 demands a specific kind of trust between a given application's makers and users. Desktop software, such as Microsoft Word and the Thunderbird e-mail client, is the same day-to-day. Not so with Web 2.0. One can log on to Gmail or Yahoo Mail and find that the interface has radically changed and that the arrangement and filtering of one's e-mail has been altered.

Mark Gerstein
New Haven, CT

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We look forward to receiving your entries.

10 Ways to Think about Innovation

What successful young technologists know



Each year, we choose the 35 innovators under the age of 35 whose new technologies seem most gloriously creative and most likely to expand human life. (We describe the 2006 winners beginning on page 43.) In editing this year's TR35—and rereading the profiles of last year's winners, whom we introduced in the October 2005 issue—I've noticed a few things about successful innovation.

(1) Successful innovators are famously untroubled by the prospect of failure. Bryan Cantrill, an engineer at Sun Microsystems who invented software that allows systems engineers to track bugs in real time (and whom we named one of 2005's TR35), says, "People who have innovated once, and who say they are not frightened that they won't be able to repeat their success, are probably lying. The challenge is not to be crippled by fear, but allow it to drive you forward." More profoundly, (2) many innovators *appreciate* failure. Yael Maguire, the chief technology officer of ThingMagic and another of last year's TR35, who has designed machines that read radio frequency identification chips, says, "If you're not working on technologies that are going to fail, you're not pushing the boundaries enough. Even if a technology failed ... you'll be able to put it in your back pocket and use it for some other purpose."

(3) Innovators commonly recognize that "problems and questions are the limiting resource in innovation," says Ed Boyden, a Stanford University neurobiologist and one of 2006's TR35 *(p. 52)*. He means that difficult questions are thrilling: "If we take a really hard question, like 'What is consciousness?' or 'How do we store memories?', it's not even clear how we should even approach the problem." In attempting to answer such questions, Boyden used genetic engineering to create a precise, reliable neural switching system; scientists could use it to study how brains function, and it might one day provide treatments for Parkinson's disease, blindness, and depression.

Boyden illustrates another theme: how (4) innovators find inspiration in disparate disciplines. The brain is "the ultimate computer," says Boyden, who has applied lessons to human neurobiology that he gleaned from his earlier work in computer science and electrical engineering.

Here are a few other general rules: (5) Innovation flourishes when organizations allow third-party experimentation with their products. Astonishingly, the fruitfulness of an open society is still unappreciated by some commercial technologists: "To this day, there are few technologies that are open," says Paul Rademacher of Google, a 2006 TR35 winner *(p. 69)*. Before joining Google, Rademacher hacked the code behind Google Maps so that other computer programs could work with it, transforming the search firm's application into a blank canvas for software developers and a social network for users. Also, (6) fragility is the enemy of innovation: systems should boast broad applications and be unbreakable. "Everything is about resiliency and robustness," says Ben Zhao of the University of California, Santa Barbara, one of 2006's TR35 *(p. 49)*. Zhao builds overlay networks, peer-to-peer networks that are less specialized than Napster and the like—and also stronger, because there are strict rules about which machines can talk to which.

(7) Real innovators delight in giving us what we want: solutions to our difficulties and expansive alternatives to our established ways. (8) They are, it is true, sometimes perplexed by our ignorance of our own needs. "You have to solve a problem that people actually have," says Joshua Schachter, the founder of del.icio.us (now a division of Yahoo) and the popularizer of Internet "tags." "But it's not always a problem that they know they have, so that's tricky." There is, however, an escape from this conundrum. (9) Successful innovators do not depend on what economists call "network externalities" (where a system, like a fax machine, has little use to its first user, but becomes increasingly valuable as more people use it): "Ideally, the system should be useful for user number one," says Schachter, our 2006 Innovator of the Year *(p. 44)*. Hence, innovators can divine needs by applying a utilitarian imperative: they ask, Would the innovation help someone *now*?

This suggests a last point: (10) many innovators become technologists because they want to better the world. Shiladitya Sengupta, an assistant professor in the Harvard-MIT Division of Health Sciences and Technology and one of 2005's TR35, who has built nanoscale drug-delivery devices for the treatment of cancer, says, "You can do top-notch research, but at the end of the day, it should actually benefit mankind." Christina Galitsky, a research associate at Lawrence Berkeley National Laboratory and this year's Humanitarian of the Year *(p. 60)*, would agree. She has demonstrated how an efficient stove can mitigate the danger that Sudanese refugee women face collecting firewood, and she has designed a cheap filter material that could remove arsenic from the drinking water of Bangladesh. "At least now I'm doing something," she says.

Jason Pontin

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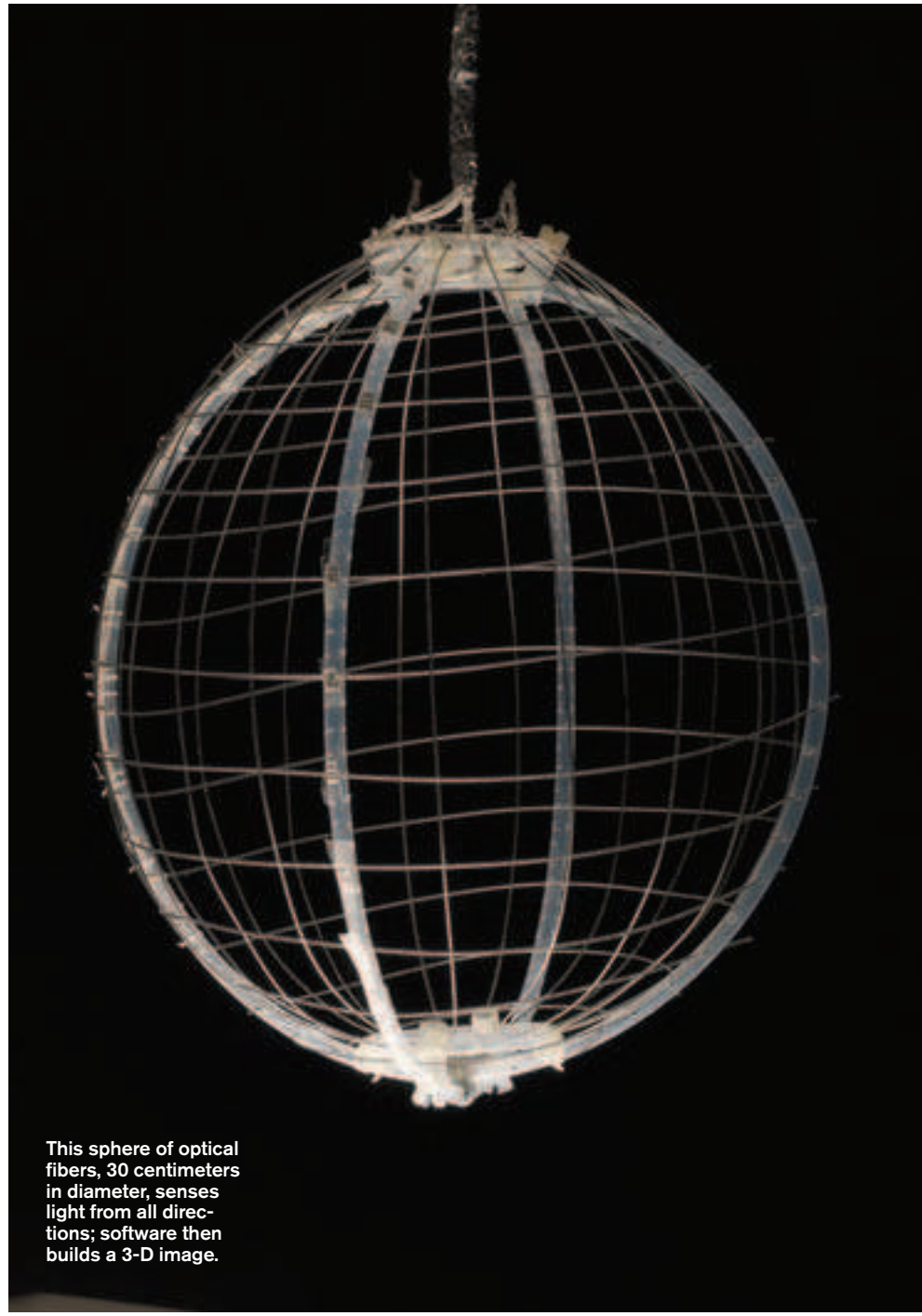
Forward

MATERIALS

An Eye on Everything

Optical fibers in a sphere could lead to clothing that "sees"

What would it be like to have eyes in the back, sides, and top of your head? Researchers at MIT have built a spherical optical system that can record images from all directions. Photons strike the sphere's network of 900-micrometer-wide polymer and glass composite fibers and penetrate a transparent cladding to a photosensitive semiconductor material at the fiber's core. An algorithm analyzes the resulting signal and constructs an omnidirectional image; it can also pinpoint the direction of a light beam based on where it entered and exited the sphere. For now, the prototype is used mainly to test materials that can at least crudely discern surrounding objects and thus might be useful in soldiers' uniforms. The researchers are working on algorithms that build clear images even if the sensors take unusual shapes, as they would when integrated into clothing. Future applications could include surveillance, with a sphere replacing multiple cameras. Ayman Abouraddy of MIT's Research Lab of Electronics says his team, directed by materials scientist Yoel Fink, expects to have a prototype of an optical-fiber mesh—using fibers 200 micrometers wide—next year. **KATE GREENE**



This sphere of optical fibers, 30 centimeters in diameter, senses light from all directions; software then builds a 3-D image.

COURTESY OF GREG HREN



Here comes the stolen movie image (right), thwarted by antibootlegging technology.

DIGITAL RIGHTS

Movies That Fight Back

New technologies battle bootleggers' camcorders

In a few years, if you're in a theater watching some sci-fi robot thriller, a real-life battle of the machines might unfold quietly before you: gadgets at the front of the house may seek out the optical signatures of bootleggers' camcorders, then fire narrow beams of light directly into the lenses, blinding the cameras and saving the day for Hollywood's bottom line.

With the Motion Picture Association of America estimating that piracy of newly released movies involves in-theater camcorders 90 percent of the time, a counter-offensive is taking shape. Technology prototyped by researchers at the Georgia Institute of Technology in June exploits the fact that all digital cameras use light-catching sensors that also reflect light back. The Georgia Tech system shines a weak infrared beam—invisible to humans—into the audience and identifies cameras by the reflected infrared light. If the system spots a camcorder, it zaps it with a narrow beam of white light, producing large splotches on the recording. Gregory Abowd, the computer scientist who led development of the technology, has launched a startup company to commercialize it, DominINC.

A different approach comes from the Content Security subsidiary of Paris-based Thomson, which opened a demo center in Burbank, CA, this year. Its technology damages illicit recordings by doctoring the movies themselves, digitally inserting extra frames containing things like flashes of light or the words "illegal copy," says chief technology officer Jian Zhao.

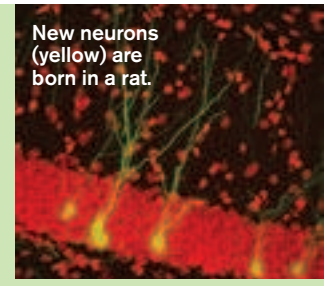
The inserted frames are undetectable to people in the theater, but because of the difference between movie and video frame rates, they show up in the pirated copies. The doctored frames appear at random rates so bootleggers can't beat the system.

Brad Hunt, chief technology officer for the Motion Picture Association, says the industry wants to make sure such technologies won't distract moviegoers. But with hundreds of millions of dollars on the line, the industry is eager for solutions in the next several years, he says. **KATE GREENE**

BIOTECH

Drugs for Brain Growth

Scientists already know that some drugs boost the growth of new neurons in the brain. Antidepressants, for example, trigger the birth of brain cells in an area involved in learning and memory, which might play a role in the drugs' ability to fight depression. Now, companies are seeking compounds that are better at enhancing the brain's ability to grow new cells. This could improve treatments for diseases like Alzheimer's and Parkinson's, as well as depression. **EMILY SINGER**



New neurons (yellow) are born in a rat.

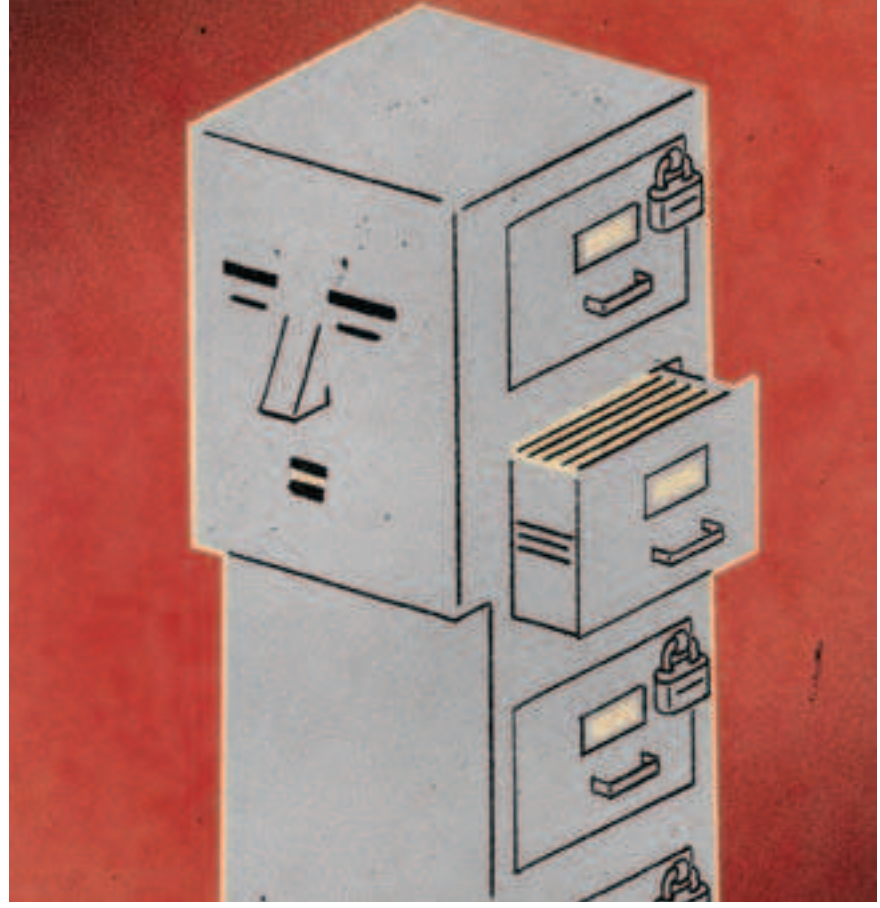
Company	Primary target	Approach	Status
NeuroNova Stockholm, Sweden	Parkinson's disease	Screening compounds for their ability to boost growth of new neurons	Human testing of two compounds, including one that could treat Parkinson's disease, is expected next year.
Neuronascent Clarksville, MD	Alzheimer's disease	Screening compounds for their ability to convert neural stem cells into mature neurons; assessing how long newly born neurons survive	Animal testing of promising compounds is expected this year.
BrainCells San Diego, CA	Mood disorders	Assessing how compounds affect the differentiation of neural stem cells into neurons or other types of brain cells	Scientists have shown that approved antidepressants exhibit a unique effect on neurogenesis.

COURTESY OF THOMSON (MOVIES); COURTESY OF BRAIN CELLS, INC. (BRAIN GROWTH)

SOFTWARE

Smart Pages

Xerox technology protects sensitive digital information



Your doctor needs access to all the medical data in your file, but you don't want the insurance clerks seeing your blood results; besides, that could violate federal privacy laws. Billions of documents—from banking records to personnel files—present similar concerns, which makes for "a pretty gnarly security problem," says Jessica Staddon, manager of security research at the Palo Alto Research Center (PARC), the Xerox subsidiary in California.

But scientists at PARC and Xerox's research laboratory in Webster, NY, are making progress with a technology that automatically protects and selectively reveals information contained in documents, without creating multiple versions of them or hogging as much memory as today's encryption programs do. In essence, the Xerox software analyzes language to determine whether words and phrases (like "alcohol abuse" or "HIV"), taken in context, are private and should be reserved for doctors, or whether, say, a string of nine digits—potentially a Social Security number—should be seen only by a personnel officer. A single stored form or document reveals its parts according to users' authorization levels: someone in the hospital scheduling office might see only a patient's address and phone number.

The researchers are working to make the core technology compatible with existing formats, including PDFs and customized hospital forms. "We've scoured the landscape, and there is no technology out there that marries content analysis with encryption so that the whole process becomes automated," says Shriram Revankar, who heads Xerox's smart-document lab in Webster.

Such technology is badly needed, says Kenneth H. Buetow, director of the National Cancer Institute's Center for Bioinformatics in Bethesda, MD. Current privacy laws make it difficult for researchers to share patient data from medical trials. "It represents a potential solution to the sharing of information in compliance with human subjects' privacy protections," says Buetow, who is assembling a cancer research database. He cautions that the technology is still unproven; but Xerox hopes it will be ready to commercialize in two to five years. **TOM MASHBERG**



COURTESY OF PHILLIPS RESEARCH (TOURNIQUET); DAVID PLUNKERT (SMART PAGES)

MEDICINE

Ultrasonic Tourniquet

A proposed lifesaving cuff would use sound to cauterize a bleeding blood vessel on the battlefield. The U.S. Defense Advanced Research Projects Agency (DARPA) earlier this year launched a four-year project to develop such a device, which would use ordinary ultrasound imaging technology to detect a broken vessel and intensely focused ultrasound to effectively seal its ends with heat. Much of the vessel would remain unharmed, thanks to the cooling effect of the blood inside it. Seattle-based Therus has been developing a similar system to seal punctures in the femoral artery that result from catheterizations. And high-intensity ultrasound technology is already approved in some parts of the world to ablate prostate tumors. The challenge: getting everything working in one small, rugged instrument. DUNCAN GRAHAM-ROWE



SpaceX's Falcon 1 rocket sits on a launch-pad on the Kwajalein Atoll in the Pacific Ocean earlier this year.

SPACE TRAVEL

The Rockets Are Coming

A flurry of launches makes 2006 a big year for private spacecraft

When Las Vegas hotel magnate Robert Bigelow launched a small prototype of an inflatable private space-station module from a Russian launchpad in July, it was only the first in an expected flurry of private launches in 2006. Progress in small, reusable rockets will make this a watershed year for private launches, perhaps ushering in an era of inexpensive space travel. "We have new items on the real road to practical spaceflight—private market development—popping up," says Boston-based aerospace consultant Charles Lurio.

The loudest roars might be heard in October in New Mexico, at the X Prize Cup, a showcase for new rocket technology and a follow-up to the 2004 awarding of the $10 million X Prize for back-to-back private manned launches that reached suborbital altitudes and returned safely. That prize went to *SpaceShipOne*, made by Scaled Composites of Mojave, CA.

The X Prize Cup will feature a new challenge: a NASA-sponsored contest that includes a $2.5 million prize for demonstrating a rocket's ability to take off and land vertically and move sideways while aloft. Four teams have registered for the contest, which is aimed at developing new spacecraft that could evolve into cheap and rugged moon-landing vehicles. Two of the expected competitors are Armadillo Aerospace of Mesquite, TX, and Masten Space Systems of Mojave, CA.

And Space Exploration, or SpaceX, founded by PayPal cofounder Elon Musk, expects to try again in November or December to launch its Falcon 1 rocket from the Kwajalein Atoll in the Pacific Ocean, after an attempt earlier this year failed. The company seeks a successful launch and landing in the Pacific.

SpaceX is mounting the only concerted effort to develop rockets that could actually put satellites or astronauts into orbit in the near term. To that end, the company plans to begin test firings of a much bigger craft, the Falcon 9, perhaps in January or February. Using nine rocket motors identical to the single motor in Falcon 1, the huge rocket could deliver payloads and people to the International Space Station (ISS) or anywhere else in low Earth orbit. Commercial flights—delivering satellites into orbit—could begin in the next few years, Musk says.

Finally, the Spaceship Company, a partnership between Virgin Galactic's Sir Richard Branson and Scaled Composites founder Burt Rutan, is expected to launch its suborbital tourist spaceplane by 2008.

Still more rockets may be soaring soon under a NASA project called Commercial Orbital Transportation Services, which is "really a sea change for NASA," says Musk. Companies are competing under COTS for contracts to develop alternative ways to get astronauts to the ISS once the space-shuttle program comes to an end in 2010. **DAVID CHANDLER**

COURTESY OF SPACEX

ENERGY

Ethanol vs. Biodiesel

Diesel from soybeans is a far better biofuel bet, research shows

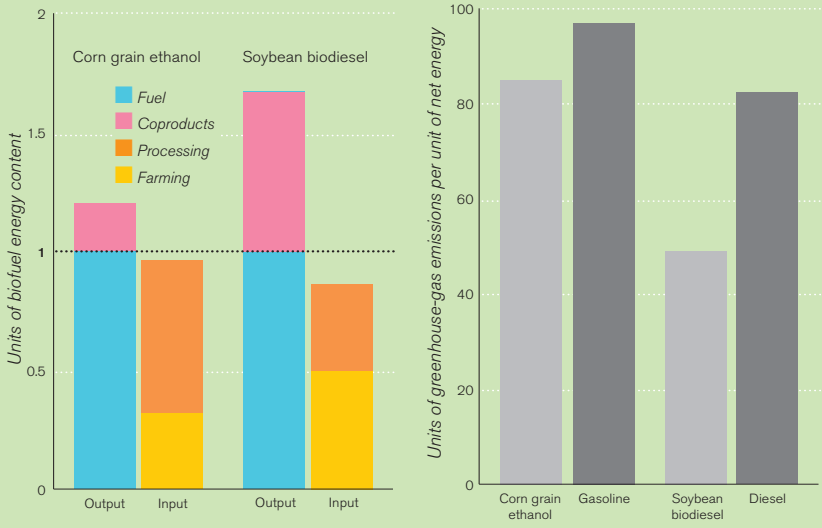
Amid a U.S. ethanol boom, new research offers another take on the long-debated question of whether corn grain ethanol provides more energy than its production consumes. A recent study that takes into account all the energy used in farming and processing corn to make ethanol concludes that there is a small energy gain, but that the gain from using soybeans to make diesel is far greater—and that biodiesel is less of a greenhouse-gas polluter, too. **KEVIN BULLIS**

Energy in, energy out

Farming and processing corn grain to make ethanol yields about 25 percent more energy—in ethanol and coproducts such as animal feed—than it consumes. In contrast, biodiesel and coproducts yield 93 percent more energy.

Greenhouse-gas emissions

Producing and burning ethanol results in 12 percent less greenhouse-gas emission than producing and burning gasoline. Producing and burning biodiesel from soybeans offers a 41 percent reduction compared with regular diesel.



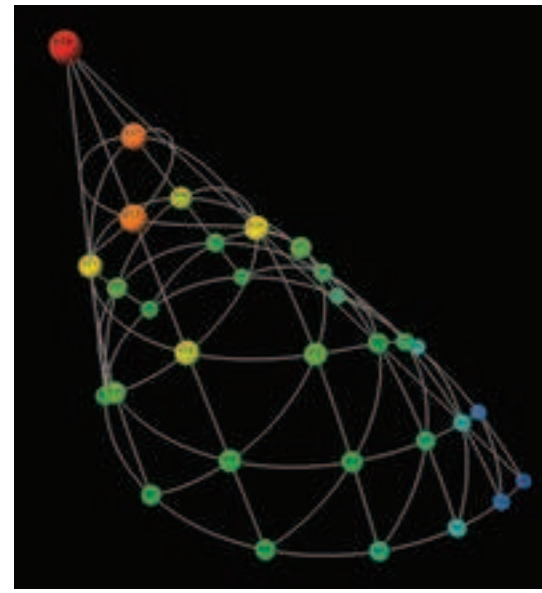
Source: Jason Hill, University of Minnesota, Proceedings of the National Academy of Sciences

INTERNET

Google vs. Malware

This summer Google started actively trying to warn users away from dangerous places on the Internet. If you try to click on a link furnished by a Google search, you might get a screen that screams, "Warning—the site you are about to visit may harm your computer! You can learn more about malware and how to protect yourself at StopBadware.org." Eventually, a general warning will be replaced by detailed information on a given site's record of distributing code that aims to steal data, send spam, or generate pop-up ads. Such records are being compiled by StopBadware.org, a creation of researchers at Harvard Law School's Berkman Center for Internet and Society and the University of Oxford (with the backing of Google and other companies).

But given that a mini-industry in "search optimization" has sprung up as online companies try to get their sites ranked higher in Google search returns, how long before malware purveyors create an industry in malware-detection-avoidance optimization? **DAVID TALBOT**



COURTESY OF DMITRI TYMOCZKO

SOFTWARE

Seeing Music

Technology has arrived that lets us see why, exactly, we like or dislike a piece of music. A Princeton University composer, Dmitri Tymoczko, says traditional Western music is attractive partly because it obeys basic music-theory rules of "voice leading"—the way notes move from one chord to the next. (The rules say the steps should be fairly small.) He created a computer program that vividly shows how far a piece of music diverges from these rules.

In the image above, generated by Tymoczko's program, each ball represents a three-note chord. The farther apart the balls are, the farther the voices have to jump between chords. As a song plays, another ball moves around the cone. If it moves in a circle, a chord pattern is repeating. If it moves from the cone's tip to its base, a piece is progressing toward dissonance.

Tymoczko says the technology could be a valuable teaching tool for musicians—showing them, for example, how a pop song is structurally similar to a Chopin prelude. And since the moving balls also allow users to watch any song "play," the program could be fun at parties, too. SUSAN NASR



TRANSPORTATION

Dashboard Watchdog

Parents fretting about their teenage drivers have a technology weapon to look forward to: a dashboard-mounted fatigue monitor that can rouse someone who seems in danger of driving off the highway. About two-thirds of drowsy-driving crashes in the United States involve drivers between 16 and 29.

Last fall, Attention Technologies, a startup in Pittsburgh, PA, introduced a webcam-sized drowsiness monitor for truck drivers, based on research at Carnegie Mellon University. It shines invisible infrared light onto a driver's retina and measures the reflection. If the reflection is blocked too often—indicating that the driver's eyes are having trouble staying open—the device flashes and beeps.

Now the company is planning a mass-market version that could sell for less than $100 (compared with up to $1,500 for the current versions), thanks largely to the falling cost of digital camera components and signal-processing chips. The company is also working on a new feature that tracks the driver's gaze angle—indicating whether he or she is actually watching the road. "We think we'll be able to get mothers to buy this for Johnny who's going off to spring break for the first time, or for their road-warrior husbands," says Richard Grace, the company's founder and CEO. He anticipates bringing the cheaper version to market within two to five years. WADE ROUSH



COURTESY OF ATTENTION TECHNOLOGIES (WATCHDOG); KEN ORVIDAS (INDIA)

INTELLECTUAL PROPERTY

India's 10-Year Patent Drive

The West begins licensing Indian-born inventions

A decade after India launched an innovate-and-patent campaign, early signs of an Indian technology invasion are evident. Just two examples: a U.S. company has purchased the patent for Indian-designed software that eliminates noise from complex digital data, and fruit growers in California and Turkey have bought a pomegranate deseeder invented by an Indian college dropout.

The patent portfolio of 38 publicly funded Indian laboratories has increased from fewer than 30 U.S. patents in 1995 to more than 720 in July of this year—and those patents are beginning to translate into licenses outside India. This growth reflects a dramatic transformation in India's research culture. For decades, most research conducted within India's closed economy was aimed at "reverse engineering"—a euphemism for copying technologies. "Without true innovation, we would always lag behind the best," says Raghunath Mashelkar, director general of the network linking the 38 public labs, known as the Council of Scientific and Industrial Research, or CSIR.

After India opened its economy in the early 1990s, foreign products slipped in—from cars to cornflakes. Industries and scientists had to com-

pete. In that changed environment, Mashelkar spearheaded a patent drive and preached a new mantra to scientists: "Patent, publish, and prosper."

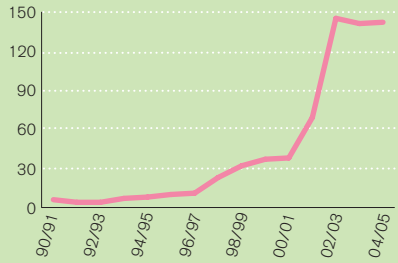
Now most scientists and labs select projects only when they see opportunities to generate intellectual property or acquire patents. Sometimes those opportunities lie in unexpected directions: one patented Indian technology—the digital noise filter—emerged because chemical engineer Bhaskar Kulkarni and his colleagues at the National Chemical Laboratory in Pune strayed off their home turf.

India's patent savvy has also enticed global companies to exploit local Indian research talent and to seek partnerships with CSIR labs. To be sure, the raw patent numbers are quite small; they pale beside the track records of global corporate behemoths like IBM (more than 2,900 patents last year) or Samsung (more than 1,600). But Mashelkar says the CSIR's labs, despite a fairly meager budget of approximately $330 million, are now garnering more U.S. patents than publicly funded laboratories in countries such as Germany, France, and Japan.

Of course, now that Cisco, Intel, General Electric, IBM, Sun Microsystems, and dozens of other companies have established Indian research centers, some fear that India's potential intellectual property will increasingly flow to multinational companies. "They're using Indian IQ to create IP for themselves," says Mashelkar. "We need to exploit our local IQ to generate IP for ourselves."

Patent Progress

U.S. patents granted to inventions from 38 labs funded by the Indian government



Source: Indian Council of Scientific and Industrial Research

Nor is everyone happy with the tempo of licensing. The CSIR has licensed only 133 patents out of 1,915 granted. "The atmosphere for venture capital in high technology in India is not as good as it is in the United States," says Ajay Sood, a physicist at the Indian Institute of Science in Bangalore. "The process of moving ideas from the laboratory to the marketplace needs to improve."

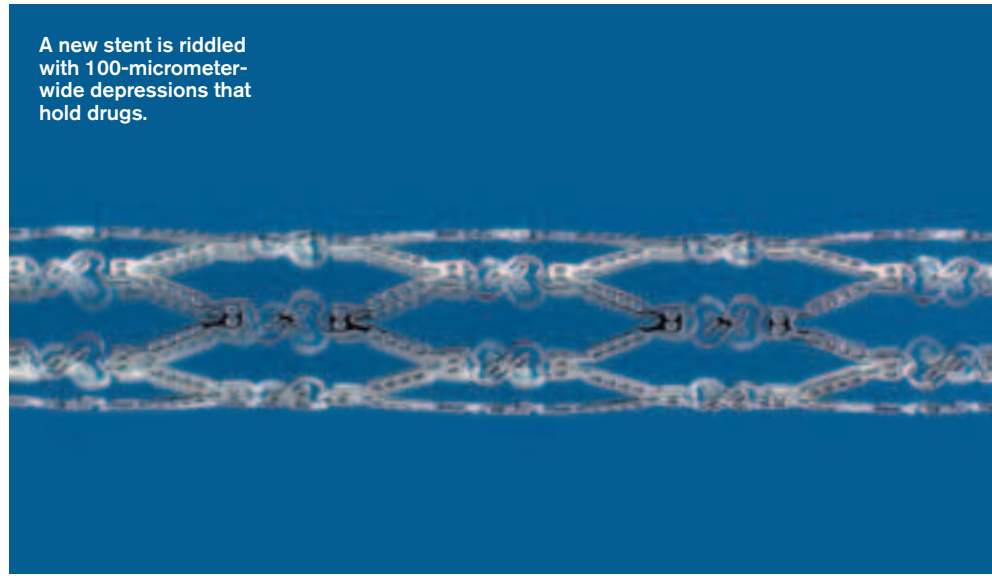
But nothing is stopping the automated pomegranate deseeder. Unlike its predecessors, the gadget—designed by Uddhab Bharali, an engineering-school dropout—does not require water to operate. As a result, "there is no dilution of fruit," boasts Chinzah Lalmuanzuala, an official at the National Innovation Foundation, an agency trying to promote grassroots inventions. **GANAPATI MUDUR**

MEDICINE

A Safer Stent

Coronary stents that secrete drugs to prevent scarring are a standard medical treatment, with more than one million implanted in U.S. patients every year. But some studies indicate that these stents—coated with a polymer that holds the drugs—may present their own problems. In March, for example, a study released by University Hospital in Basel, Switzerland, found that some patients who received them suffered higher rates of blood clotting than those using bare-metal stents.

Now, Conor Medsystems of Menlo Park, CA, believes it has a safer drug-releasing stent. Hundreds of tiny holes run along the branches of Conor's metal stent, which is made from stainless steel and cobalt chrome. Each hole acts as a reservoir for the drug-and-polymer mixture, whose proportions can be altered from one reservoir to the next. That allows different medications to be released far more precisely than is possible with today's technology, in which one coating covers the whole stent, says Conor's founder and chief technology officer, John Shanley. What's more, polymers in embedded reservoirs can be more biodegradable than existing coatings, which need to be tougher to withstand the friction of insertion. The stent has passed European trials; Conor is now conducting U.S. human trials that are expected to be complete next year. **TOM MASHBERG**



A new stent is riddled with 100-micrometer-wide depressions that hold drugs.

COURTESY OF CONOR MEDSYSTEMS

ENERGY

Carbon Ready

Sequestration science is far ahead of needed policy



Norway's Sleipner natural-gas field has sequestered carbon dioxide underground for 10 years.

COURTESY OF STATOIL

Pumping liquid carbon dioxide underground on a massive scale so it won't contribute to global warming has been talked about for years. Howard Herzog, an MIT chemical engineer and the program manager of the Carbon Sequestration Initiative, an industrial consortium, says the most recent international conference on the subject—in Trondheim, Norway, earlier this year—made clear two things: First, the geological questions are being resolved favorably. Second, without policies that put a price on CO_2, it's unlikely that any sequestration facilities will actually get built. **DAVID TALBOT**

TR: How has interest in this field grown?

Herzog: When this international conference series started in 1992, it had 250 people and less than 100 papers. We had 1,000 people in Norway, and 500 papers.

Norway was the first to enact a CO_2 tax, in 1991. How has this played out?

It sent a signal to see if there was a way to reduce CO_2 emissions and resulted in a large project in the North Sea to sequester carbon dioxide from a natural-gas field.

What do we know about its performance?

There is no indication of any leaks, and they've done some seismic tests that show the CO_2 is staying in the underground geological formation. The amount of monitoring hasn't been such that you can say for certain there are no leaks—but none has been detected.

What about the question of geologic suitability generally?

At the Norway meeting, the biggest category of papers was on geological storage. I think the work coming out says they are gaining a higher degree of confidence that this will work—and work well, if implemented with good practices.

What else is emerging on the policy front?

With a European carbon-trading system, several utilities have announced projects to build plants with CCS [carbon capture and storage], which is indicating at least at the high level that those price signals were enough to induce serious interest.

Outside of Europe, despite the lack of specific policies, there is still a lot of interest in this technology. People feel that over the next 10 years, policies will be put in place throughout most of the developed world.

What will it take to get sequestration projects built?

Utilities are not going to build them unless the policy is in place or they are really sure that policy is imminent. It's easier to announce projects than build them.

How about in the United States?

In the next three years, the chances of anything happening are negligible. But within the next 10 years, I think the chances are greater than 50/50 that we'll have some kind of carbon policy. I think no matter who is elected in the 2008 election, there will be changes.

Sampling of Proposed Large-Scale Projects to Capture CO_2

Company or consortium (location)	Fossil fuel	Fate of CO_2	Possible opening
BP (Scotland)	Natural gas	Enhanced oil recovery	2009
BP (California)	Petroleum coke	Enhanced oil recovery	2011
Statoil/Shell (Norway)	Natural gas	Enhanced oil recovery	2011
FutureGen (U.S.)	Coal	Sequestration	2012
RWE (U.K. and Germany)	Coal	Sequestration	2014 and 2016
Monash (Australia)	Coal	Enhanced oil recovery	2015
Vattenfall (Germany)	Coal	Sequestration	2015

Source: MIT Laboratory for Energy and the Environment

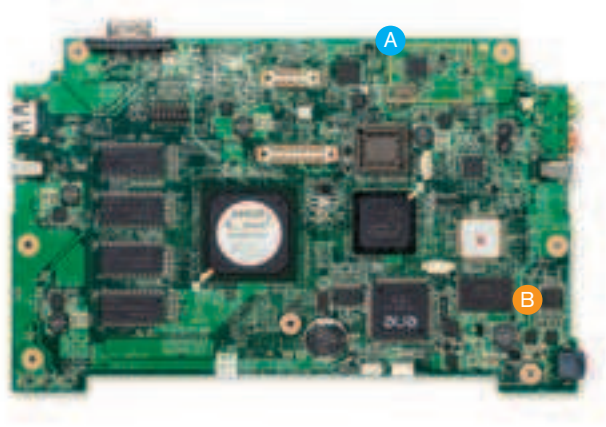


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The Hundred-Dollar Laptop

Nicholas Negroponte's machine has a working prototype. **By Daniel Turner**

Founded by members of MIT's Media Lab and led by its chairman emeritus Nicholas Negroponte, One Laptop per Child (OLPC) is working with industry to design and produce an inexpensive and durable laptop to be distributed to children in poor countries. The laptop is meant both to display many years' worth of textbooks and to connect communities wirelessly with the rest of the world. From its custom-designed, power-saving chips and displays to its built-from-scratch Linux-based operating system, the Hundred-Dollar Laptop (HDL) is a study in economy. India's secretary of education icily dismissed the laptop this summer, but Thailand will test 500 units late this year, with an eye to buying one million. Argentina, Brazil, and Nigeria have also shown interest. Pictured here is a nearly final prototype.



A Mesh Network

OLPC worked with chip maker Marvell to customize the software for the HDL's wireless chip—"a very special beast," says Mark Foster, OLPC's chief architect. The chip includes an onboard CPU and its own RAM (unlike most wireless chips), so it can run even if the laptop is turned off. This enables each laptop to be its own wireless router. As a result, each laptop will be able to act as a node in a mesh network, a nonhierarchical, self-healing network that pools the power and bandwidth of all its nodes. A small school's worth of laptops could use their bundled software to create a VoIP phone network for a village that has never had a telephone. Also, children will be able to exchange files without the need for a server.

B Flash Memory—and No Hard Drive

Hard drives require lots of power to keep their platters spinning and their other moving parts moving, so the HDL does without a hard drive, using solid-state memory instead. Thanks in part to the popularity of MP3 players, flash memory—which would have broken the HDL's budget even a few years ago—has become much cheaper. In addition, the HDL uses custom chips, designed in partnership with AMD and other companies, that offer great control over which parts of the computer stay on and which shut off at any given moment. OLPC wants to keep the CPU off 80 percent of the time; it hopes that, in total, these stingy chips will lower the HDL's power hunger to 2 watts, compared with the average laptop's 25 watts.

C High-Resolution Screen

Standard LCD screens inexpensive enough for the HDL project wouldn't have let the laptop display languages, such as Arabic, whose characters feature subtle curves. The custom-designed screen has a 1,200-by-900 gray-scale mode, which is readable in sunlight, and a backlit color mode, which offers lower resolution. Power is saved in two ways. First, the backlight uses LEDs, which use less power then the fluorescent backlights most laptops use. Second, the laptop spends a lot of time in monochrome mode, which doesn't use a backlight at all.



Custom-Designed Chips

DCON: The display controller chip acts as a bridge between the display and the rest of the system; because the chip can receive input and manage what's on the display, the rest of the system can go to sleep while the display remains on.

CAFE: The camera and flash enabler chip was first meant to be an interface for the laptop's flash memory that was faster than standard flash-memory controllers, which can't handle the continuous accessing required of a computer's main storage device. But this chip also became a controller for a built-in digital camera, which OLPC may or may not include in the laptop.

CHRISTOPHER HARTING



Human Power Source

Since its inception in January 2005, OLPC has been working on a human-powered way to recharge the HDL. One manual option is a hand-pull generator, developed by Squid Labs of Emeryville, CA. The goal is to net 10 minutes of power for every minute of pulling. OLPC has also considered treadle-, pedal-, and even rocking-chair-based power systems, and it's thought of harvesting power from keystrokes or using flywheels that produce power when a user carries the laptop.

D Ruggedization

The water- and dust-resistant HDL is meant to be used by children, and in tough environments. In addition to using solid-state memory in place of a hard drive, it has a polystyrene and rubber bumper. It may also feature a two-millimeter sheet of transparent plastic over the display.

Arthur Caplan

Who elected *you* king?

Round and brash, with the gravelly voice of a street fighter, Arthur Caplan looks and sounds more like a boxer than an ethical philosopher. The director of the Center for Bioethics at the University of Pennsylvania, Caplan has been enormously influential in a variety of debates in modern biomedicine, from the fate of Terri Schiavo to the market for organs for transplant. He has written or coauthored more than 400 peer-reviewed articles and several book on the ethics of new medical technologies.

***TR*: Why should we care about bioethicists? Are they really so influential?**

Caplan: Bioethics is most influential at the bedside. But the influence of bioethicists on research and human experimentation is also strong. Finally, conservative bioethicists have a lot of influence in Washington these days.

How much of this activity is just window dressing? Arguably, it allows interested parties to say, "Look, we've got bioethicists here! We *must* be taking care of the ethics!"

Well, that happens, but it doesn't mean bioethicists don't make a difference. Bioethics has real influence on legislation and regulation.

What debates have you most influenced?

I was involved in the National Organ Transplant Act. I singlehandedly held up the movement toward creating markets in organs. In genetics, I was the first guy on embryonic-stem-cell research. I was able to undermine the administration's argument that the president's position [which allowed federal funding of stem-cell research with cell lines that were already established] was a compromise. Since then, I've worked with patients' groups and scientists to find a moral framework for embryonic-stem-cell research.

You have not mentioned the death of Terri Schiavo. But last year it seemed you talked of little else: you were ceaselessly quoted in the media.

I was the most outspoken critic of government intervention, that's true. And I felt bullied by the president and by some members of Congress. But although we were outnumbered and outspent, it's fair to say that we won that fight. Most Americans don't want government intervention in end-of-life cases.

Why should anyone listen to bioethicists?

Critics sometimes say, "Well, who elected *you* king?" I smile and say, "If you don't like what I say, just ignore it." Look, bioethicists became influential for a reason: they were able to bridge the gaps between politicians, the media, and the sciences. But they're not a priesthood, and they don't have any authority to dictate anything to anybody.

Do bioethicists say no a lot?

We jokingly say that anyone can be a bioethicist: just say no to everything.

You are held up as an expert on everything from assisted suicide to designer babies. You give great one-liners. But your ability can at times seem facile. Does this bother you?

No—because it's a skill I have, and I'm a quick study, and I can track a lot of stuff.

Do some bioethics for us.

There are people who have argued that tamoxifen [which may be an effective treatment for breast cancer] has too many side effects, such as ovarian cancer and eye problems. They think it might be unethical to use it as a prophylactic. I don't agree. I think prevention is in some ways better than treatment. I'm not saying we should take every crazy risk, but I argued in favor of tamoxifen's clinical trials.

What are the principles that inform your opinions?

I'm a consequentialist: I'm looking at outcomes. I'm trying to decide if a particular policy—such as allowing surgeons to do face transplants—would do more harm than good.

That's not much of an answer. What *else* would you do? Do consequentialists work from first principles?

They can and do. Peter Singer [a Princeton University philosopher known for his view that acts should be judged according to whether they promote the preferences of feeling creatures, regardless of species] has his consequentialist utilitarianism, and he rigorously applies it. He says that if animals are smarter than retarded children, then experiment on retarded children. I'm not willing to trust *any* theory that far. In general, I'm not looking for fundamental truths when I discuss ethics. What matters is what is most practical at a given time. I ask, "What are the benefits and costs?" And I understand that the answer will change over time.

Scientists often look down on bioethicists. Why?

In the culture of science, the only thing that counts is the science. If you're not doing that, it means you're not smart or good enough.

Do you ever wish you had become a scientist?

I did go to medical school for a while, at Columbia. I liked it, but I don't have the patience for the level of detail that makes good science.

DAVID EWING DUNCAN

Disclaimer: Arthur Caplan is on the board of advisors of BioAgenda, the nonprofit institute of which David Duncan is the editorial director.

CHRIS CRISMAN

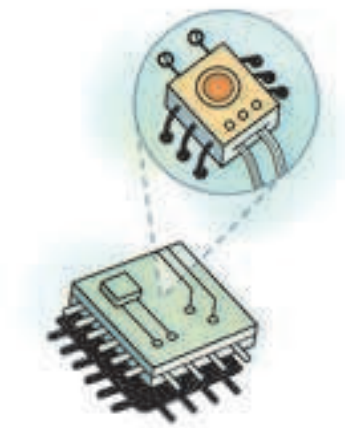


NANOTECHNOLOGY

The Future of Nanoelectronics

New materials like carbon nanotubes will complement, not compete with, conventional silicon devices, predicts **Song Jin.**

The carbon nanotubes and semiconductor nanowires that became available to scientists in the 1990s captured my imagination and attracted me to the field now called nanoelectronics. For an inorganic materials chemist like me, these newly discovered tiny building blocks were like Tinkertoys that could potentially be used to make all kinds of gadgets and widgets. The desire to build something, to invent new structures out of them, spoke to me as a chemist, and I've been fascinated by the possibilities of these new nanomaterials ever since.



Thanks to Moore's Law, however, the electronic devices produced by the conventional semiconductor process are now also "nanoelectronics." So what will be the role of new nanoelectronics based on chemically synthesized nanostructures, like carbon nanotubes and nanowires? Thermodynamics dictates that chemically synthesized nanostructures will probably never achieve the uniformity and perfection of electronic devices carved out of silicon crystals using conventional lithography. Rather, the strength of the new nanomaterials is in their chemical diversity and flexibility.

Those of us working on novel nanoelectronics should be trying to do things conventional technology simply cannot do, rather then trying to compete directly with the well-established technology. There are opportunities using physical mechanisms that have not been utilized in solid-state electronics. My research group, for example, is working on nanoscale magnetic semiconducting materials that could enable the demonstration of spintronics, which seeks to exploit the spin properties of electrons in computing devices.

The silicon microelectronics industry has been remarkably conservative, using only a very small fraction of the elements in the periodic table. For a long time, after all, reducing the size of transistors, which was made possible because of advances in the lithographic process, was sufficient to sustain the performance of devices as they were scaled down. But size reduction itself simply cannot deliver the necessary increases in performance anymore. New chemically synthesized nanostructures might be suitable for various advanced functions that are difficult to achieve with more conventional silicon-based materials.

We can imagine a future for hybrid devices, combining the strength of both approaches. In such a scenario, we would use exotic materials for new functions that are needed only at certain places on a very large-scale circuit that is generated by a conventional semiconductor process. Newly synthesized nanostructures can also compete in applications where perfection is not of paramount importance but cheap processing, chemical flexibility, and function are. Electronic biosensors in which carbon nanotubes or nanowires are used to detect specific molecules are certainly one of those promising areas, but there may well be others that we have not imagined yet.

How can we organize these new nanostructures and integrate them into useful systems? This is an enormously challenging problem, and though I have worked on it before, I do not pretend that we have fully addressed it. But now that researchers have the Tinkertoys in hand, we can begin to come up with more creative ideas and strategies to manipulate these building blocks. TR

Song Jin is an assistant professor of chemistry at the University of Wisconsin–Madison. He is a member of this year's TR35 (see p 47).

INFORMATION TECHNOLOGY

Development Powered by Education

Matthew Herren says interactive tools could prepare students in developing countries for the collaborative workplace of the future.

Imagine for a moment that you have one chance to pass a driving test; if you fail, you can never reapply for a license. You ask for the material you will be tested on and are told you can see it only briefly, peering over someone else's shoulder. No one has trained you to operate an actual car. And when it is time to take the test, you are blindfolded. The result will, of course, be catastrophic.

This isn't a bad analogy for the challenges facing a typical African elementary- or secondary-school student, even though most world political leaders and development specialists agree that the future of African nations lies in education. African schools teach toward set exams, which determine who passes and who leaves school. It is a system that does not foster much creative thought but in its own way ensures

ILLUSTRATIONS BY HARRY CAMPBELL



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certain standards. Or would, if access to educational materials were equal throughout all schools.

But it is not. Educational materials are expensive to print and to supply to remote rural schools. Senegal is typical: school textbooks cost two to three times what poor families can afford, so only one in five students receives them.

There is an alternative. Using digital satellite radio to connect to a content distribution network, students could download new material—as soon as it becomes available—to small handheld computers recharged with solar power or crank chargers. Then they could take it home to read at night, on a backlit screen, even in homes without electricity. That is the technology my company, EduVision, has been developing for the last two years.

Not only would such a distribution system get more, and more current, material to more students, but it would also introduce students to an important new approach to learning and working. Students who compete throughout their school years for top ranking will not be prepared for workplaces where collaboration is becoming far more important. An electronic environment for group work—a textbook wiki of sorts, in which students around the world can compare notes and share information—could teach collaboration at the same time that it teaches academic material itself.



In the future, students in schools throughout the developing world will communicate and interact to solve problems and complete assignments. They may be in the same class or school, or they may be in different countries. They may never meet in person, but they will form close connections and learn to work in teams. They will also have access to vast libraries of content where they can find solutions, answer questions, and explore the life of the mind. TR

Matthew Herren is founder and chief technology officer of EduVision, an e-learning company based in Zürich, Switzerland. His TR35 profile is on p 64.

BIOTECHNOLOGY

Finding Evolution's Signatures

Comparing genomes of different animals, explains **Manolis Kellis**, allows scientists to decipher hidden elements in the human genome.

Though researchers have finished sequencing the human genome, it is still far from understood. A major objective of biotechnology is to develop the experimental and computational tools necessary for deciphering the signals encoded within the genome and to understand their role in human health and disease.

Much remains unknown. It is still a matter of debate exactly how many genes the genome encodes, or even how a gene should be defined. In addition, scientists are just beginning to understand the array of regulatory sequences that punctuate the genome and dictate when certain genes are turned on and off. The complex code within these elements has yet to be deciphered.

Comparative genomics can shed the powerful light of evolution on these unknowns. Functional regions of the DNA sequence, such as genes and regulatory regions, have been well conserved, remaining largely unchanged across related species through millions of years of evolution; but DNA sequences that do not code for genes or regulatory regions change more rapidly. To help us understand the evolutionary constraints of functional elements in the human genome, the National Human Genome Research Institute has recently expanded its sequencing efforts to include additional mammalian genomes.



In my group, instead of simply searching for highly conserved elements, we search for elements that have changed in particular ways. By comparing various genomes, we have found several evolutionary signatures—common patterns in the way a particular DNA sequence has evolved over time. We are now using these evolutionary signatures to reanalyze the human, yeast, and fly genomes and have already uncovered hundreds of novel genes, novel exons, and unusual gene structures.

We have also used genome-wide conservation patterns to define subtle regulatory motifs that are another type of evolutionary signature. Coupled with rapid string search algorithms, these signatures have led to the discovery of a complete dictionary of known and novel regulatory elements in the human, yeast, and fly, revealing the building blocks of gene regulation.

These evolutionary signatures are universal across kingdoms of life. With complete genomes, we can use them to elucidate common evolutionary principles, interpret our genome, study human variation and evolution, and revolutionize our understanding of human biology. TR

Manolis Kellis, one of the TR35 (see p 58), is an assistant professor of computer science at MIT.

Energy...

New Section on Technologyreview.com



In late September, Technology Review will introduce its new online Energy Channel, which will focus on the most important energy-related technologies for the 21st century. From solar technology and biofuels to more efficient ways to burn fossil fuels and safer ways to build nuclear power plants, we'll explore the most promising energy technologies—many of them ready now. To get even more timely insights and authoritative analyses, sign up for our free weekly Energy Newsletter and view our video "Global Warming" at:

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Photo Essay

NASA's New Cameras

One of the primary missions of NASA's most recent spaceflight, the space shuttle *Discovery*'s July trip to the International Space Station, was to test new safety technologies. While the shuttle orbited 300 to 400 kilometers above Earth, astronauts tried out new cameras designed to detect damage that the shuttle's protective tiles might sustain during the trauma of leaving Earth's atmosphere. Two astronauts inched out to the end of the shuttle's 100-foot robotic arm and boom to test their stability as a tile repair platform. Astronauts inside the shuttle and in the space station photographed the project through their windows.

By Katherine Bourzac Photographs courtesy of NASA


Canada



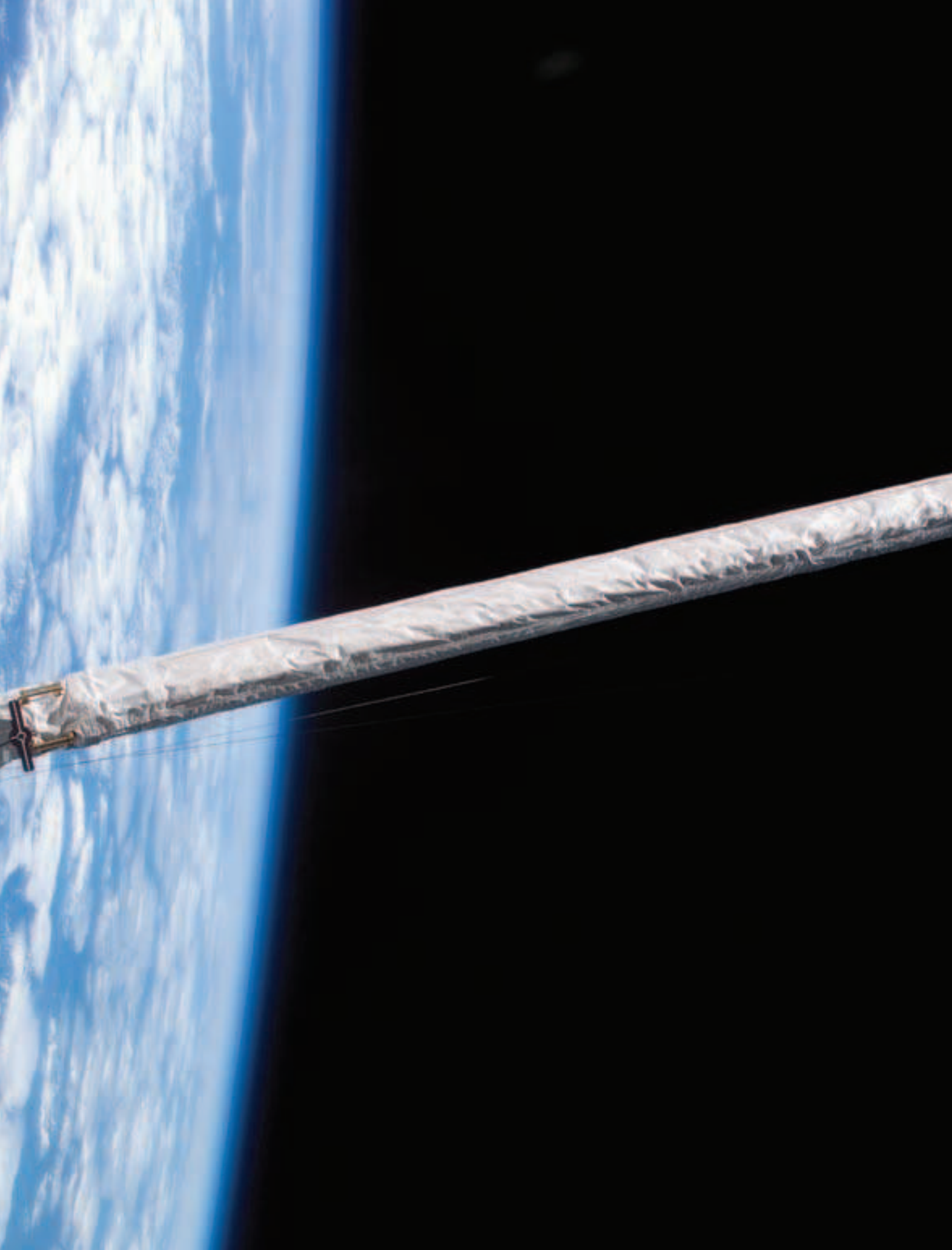
On the day after the launch, *Discovery* astronauts unpacked the shuttle's 50-foot robotic arm from the payload bay. Part of the arm and the shuttle's wing are visible at right in a photo taken above the Gobi Desert. The arm has shoulder, elbow, and wrist joints; on the end is a grappling device that holds a 50-foot boom extension. This extension and its cameras were new to the shuttle, installed in response to the *Columbia* disaster, which was caused by damage to insulation tiles on the shuttle's skin. *This page:* There are four sensors at the end of the boom: a laser dynamic range imager, which is used to make an initial scan of the shuttle to detect damage; a TV camera that helps astronauts orient the 100-foot arm and boom; and for a more focused inspection of suspicious areas, a conventional digital camera and a laser camera that can take 3-D pictures. The redundancy in the functions is intentional: if one camera should fail, the others will still do the job. The 100-foot arm and boom can photograph the entire shuttle; astronauts and NASA scientists on the ground inspect the photos for evidence of damage to the shuttle's protective tiles, found on the nose, belly, and wings' leading edge.

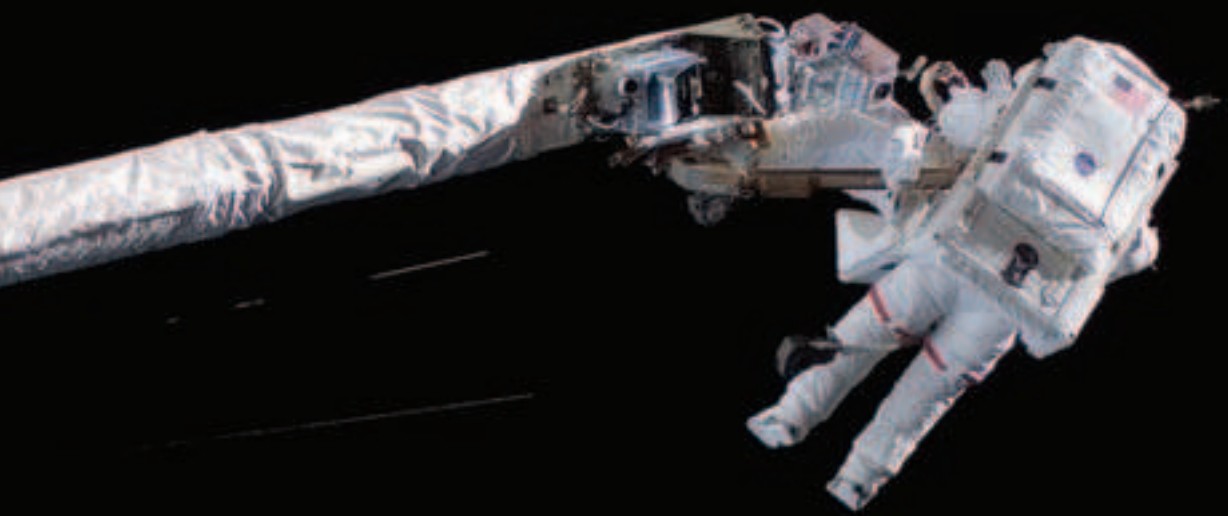


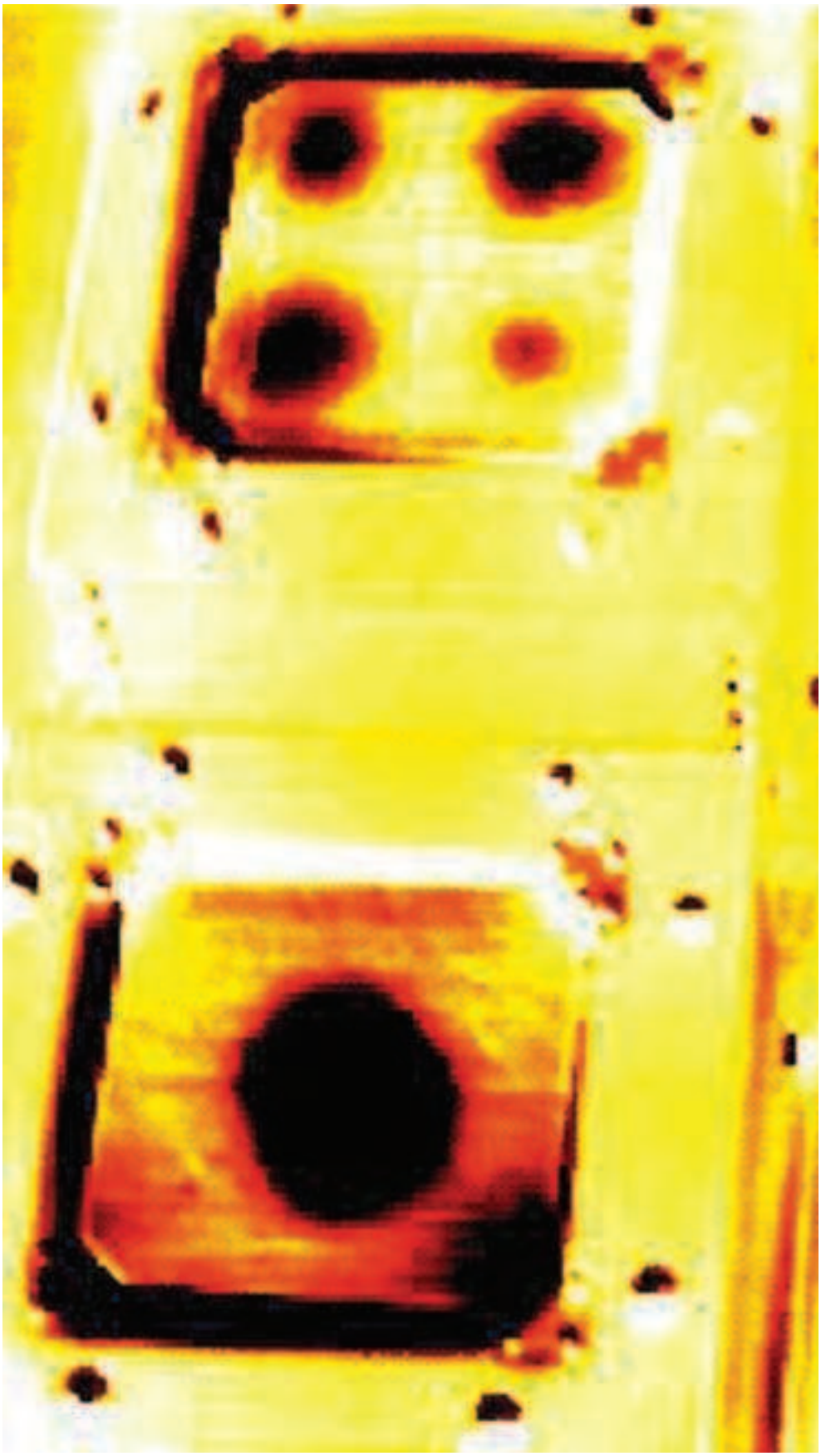
After photographing the shuttle's surface to look for damage, astronauts docked at the International Space Station. At left, the station's own robotic arm—extended horizontally at the top of the image—has just unloaded a tank of supplies from the shuttle's payload bay, whose door is still open. *This page:* While astronauts are moving the shuttle's robotic arm, the laptop at left generates a graphic representation of its position in real time. Without this representation, the astronauts would have a harder time moving the arm; their guidance would come solely from the cameras on the arm and from those in the payload bay, which produce the images shown on the two screens on the right. The arm can be moved via hand controllers, or its movements can be programmed into a computer. Some of the imaging equipment is held down with duct tape. "We could not fly into space without duct tape," says NASA engineer Bruce Sauser.



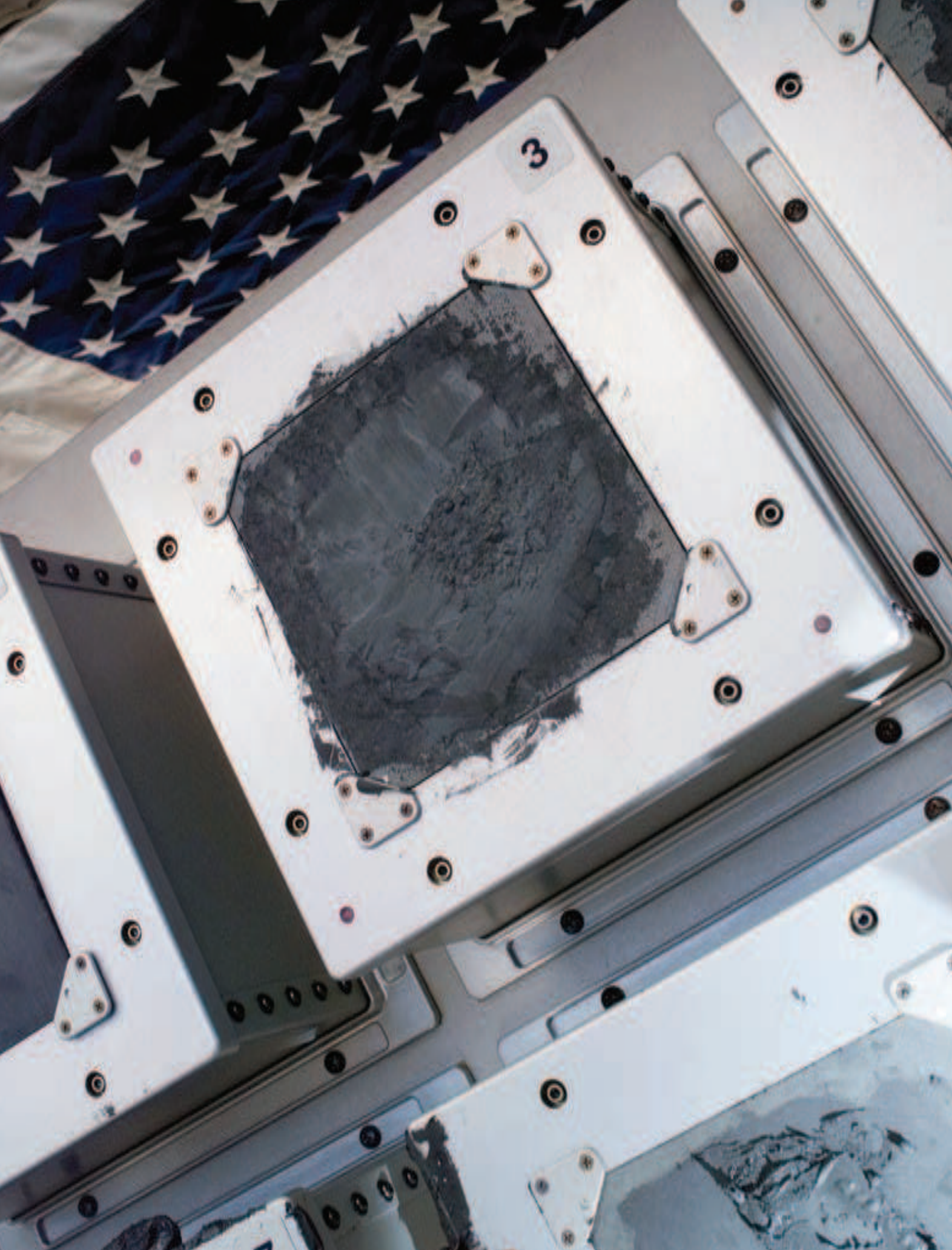
Repairing insulation tiles was not an option on previous missions, because without a boom, parts of the shuttle were beyond the reach of its robotic arm, and in any case, there were no methods for repairing damaged tiles. Future astronauts will be able to repair shuttle tiles while perched on the end of the boom; during the most recent mission, astronauts tested its stability as a work platform. Accelerometers on the robotic arm recorded vibrations and flexing, and astronauts reported in real time on their comfort level. Some of the data is still being processed, but NASA engineers feel confident that the boom is stable enough to serve as a work platform during the 15 planned shuttle missions to the space station. *This page:* An astronaut touches the space station during a stability test. *Opposite:* Astronauts were tethered to the arm by spring-loaded reels and cords and could secure themselves on the end of the boom with foot restraints.



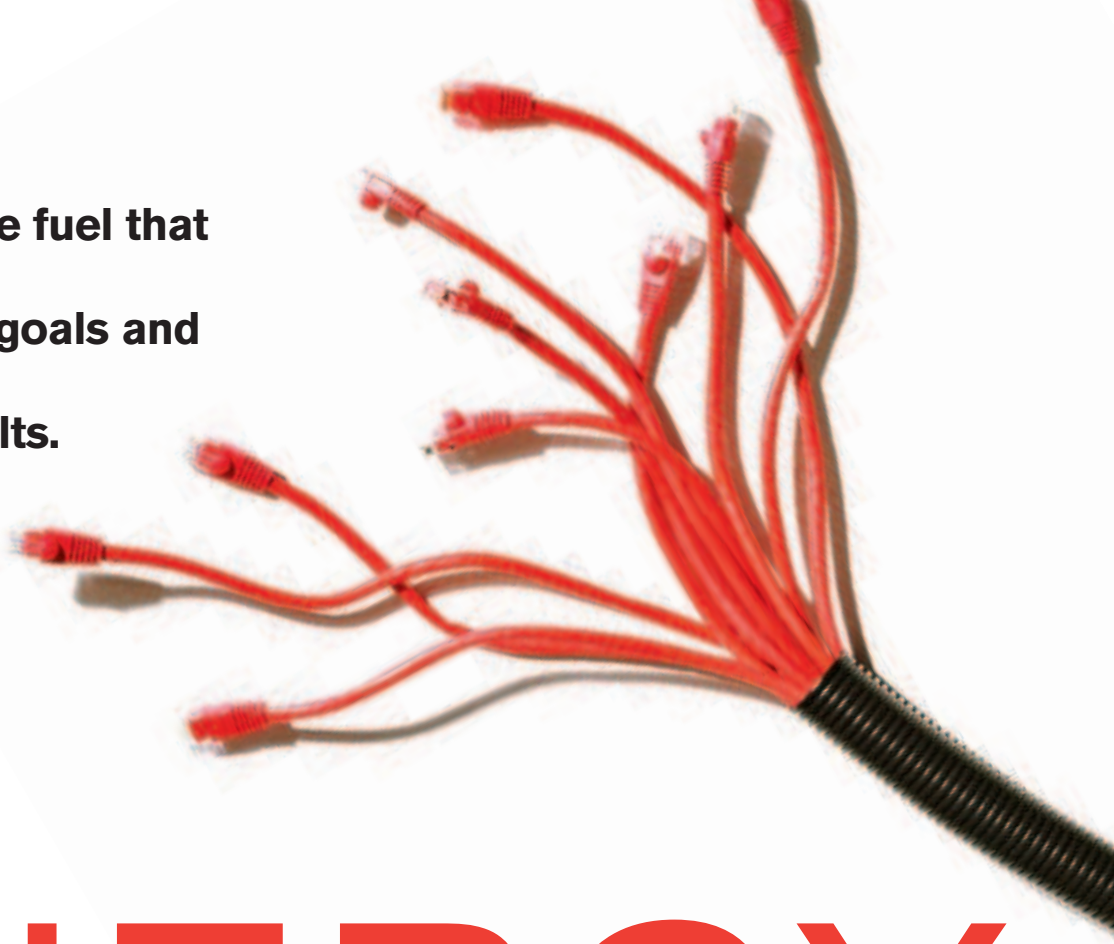




On the ground, NASA engineers created a set of sample damaged tiles. In the payload bay with the doors open, astronauts took infrared photographs of them (left) to make sure the camera worked when exposed to the rigors of space. Infrared images can detect internal damage, like the black spots seen in these two tiles. *Opposite:* Also in the payload bay, astronauts practiced repairing damaged tile samples with a new putty formulation. They assessed how easy the putty was to dispense and spread in space. When the shuttle returned, the repaired tiles were tested to determine whether they could withstand the extreme temperatures associated with reëntering the earth's atmosphere. At press time, two tiles had been tested and had passed.


3

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**Past TR100/TR35 honoree*

Since 1999, the editors of *Technology Review* have honored those young innovators whose inventions and research we find most exciting; today that collection is the TR35, a list of 35 technologists and scientists, all of them under the age of 35 (as of September 1, 2006). We begin by publicly soliciting nominations from around the world and collect as much information as possible about each nominee. We rely heavily on the expertise of a distinguished panel of judges (left)—several of them former winners themselves—to help us whittle down the group of nominees and select the very best to honor. Though the process is arduous, it's also immensely rewarding: the work these innovators do provides a good look at both the present and the future of technology.

Apostolos Argyris p. 53
Prithwish Basu p. 56
Jeffrey Bode p. 67
Edward Boyden p. 52
Seth Coe-Sullivan p. 57
Utkan Demirci p. 67
Roger Dingledine p. 66
Stefan Duma p. 63
Jason Fried p. 50
Christina Galitsky p. 60
Matthew Herren p. 64
Song Jin p. 47
Manolis Kellis p. 58
William King p. 50
Eddie Kohler p. 57
Ram Krishnamurthy p. 58
Stéphanie Lacour p. 65
Ling Liao p. 47
Ashok Maliakal p. 55
Jane McGonigal p. 50
Joshua Napoli p. 59
Liam Paninski p. 48
Nikos Paragios p. 70
Michael Raab p. 69
Paul Rademacher p. 69
Anand Raghunathan p. 70
Joshua Schachter p. 45
Jay Shendure p. 53
Sumeet Singh p. 47
Paris Smaragdis p. 48
Marin Soljačić p. 64
Alice Ting p. 55
Christopher Voigt p. 55
Michael Wong p. 49
Ben Zhao p. 49

Internet
Nanotechnology
Software
Biotechnology
Hardware
Energy
Telecom
Transportation

The members of the 2006 TR35 are solving long-standing problems—finding ways to build ultrafast computer chips that won't melt down, for instance—and creating entirely new technologies, such as electronic skin. Their innovations address both quotidian concerns—cell-phone security, auto safety for pregnant women—and lofty goals—weaning the world off oil, improving education in Africa. Yet each is changing the world in his or her own way, just as our past winners did. Getting to know these innovators is one of the highlights of our year; we hope you enjoy learning about them as much as we have. *—The Editors*



INNOVATOR OF THE YEAR

Joshua Schachter, 32

Del.icio.us (Yahoo)

How tags exploit the self-interest of individuals to organize the Web for everyone. **By James Surowiecki**

In 2001, a wonky Wall Street quantitative analyst named Joshua Schachter had a problem. In the late 1990s, he'd started a website called Memepool, which was a simple collection of Web links that he had found interesting, useful, or both. Over time, as Memepool's users began sending in links they thought the site should feature, Schachter's personal list of bookmarked Web pages grew to more than 20,000 entries, far more than any folder system could handle. To bring some order to the chaos, Schachter wrote an application called Muxway, which allowed him to manage his links by giving each a short label, or tag—enabling him to call up all the pages that were tagged, say, "Wi-Fi" or "math."

People continued to view Schachter's list of interesting links; but now, because of Muxway, those links were organized around tags. Pretty soon, about ten thousand people every day were stopping by. Schachter realized that even with (or perhaps because of) the deluge of information available on the Web, people were still hungry for good links, and they were interested in finding out what others thought was interesting. He also figured that if tagging was helpful to him, it could make storing and finding bookmarks easier for everyone else. So with that in mind, he rewrote Muxway, and in 2003 he launched it as a website called del.icio.us. Within a couple of years, hundreds of thousands of people were using del.icio.us, and it had metamorphosed into a system for organizing not just individuals' information but the whole Web. Today it exemplifies the promise of what's often called Web 2.0—websites and online applications that rely on user participation to achieve their greatest value.

At its core, del.icio.us is a bookmarking system: a place to store all those links that don't fit in a "Favorites" folder. But it took off because it offers everyone what Muxway had offered Schachter: a way not just to collect links in one place but also to organize them. As people trawled the Web, they could tag interesting pages using whatever words they wanted, and del.icio.us would keep track of them all.

"You bookmark for one of two reasons: either you think you're going to need that page again somewhere down the road, or you don't have time to read it now, but you want to read it later," Schachter says. "The challenge is, once you've got all these bookmarks, how do you manage them? The problem we're really dealing with is memory and recall, and using technology to make your memory more 'scalable.'"

Schachter deliberately avoided imposing any rules about how people could use tags. He knew it wouldn't work: "If I went in there and said, 'Hey, you're using that tag wrong,' people would just tell me to fuck off," he says. He also knew that letting people use their own tags—instead of choosing them from a menu he provided—would make del.icio.us more likely to be genuinely useful. Each person who uses del.icio.us is effectively coming up with an idiosyncratic system for classifying the Web: an article about, say, Dallas Mavericks owner Mark Cuban might be tagged "Mavericks" by one person, "crazy" by another, and "Mavericks" *and* "crazy" by a third. (Del.icio.us allows users to pin as many tags on a page as they want.) "If you're trying to tag a page in a way that'll get you back there someday, you want to use your vocabulary, not someone else's," he says.

Though del.icio.us has become a way for users to collectively organize information across the Web, it did not begin as anything so grand. Rather, it emerged as a way to help individuals manage their own information. "For a system to be successful, the users of the system have to perceive that it's directly valuable to them," Schachter says. "If you need scale in order to create value, it's hard to get scale, because there's little incentive for the first people to use the product. Ideally, the system should be useful for user number one." This makes del.icio.us different from systems that rely on what economists call "network externalities"—meaning they're valuable only if lots of people use them. It was hard to get the first person to buy a fax machine, because a fax machine is useless if you're the only one who has one. But even for the first person to use del.icio.us—Schachter—it worked.

As it happens, lots of people found del.icio.us valuable right from the start, making it a proverbial grassroots hit. Schachter did no advertising, no marketing. But the site

NATHAN PERKEL

was so successful that in 2005 he quit his day job at Morgan Stanley, raised some money from outside investors, and launched del.icio.us as a regular business. Less than a year later, Schachter sold del.icio.us to Yahoo, where he now works in the Groups business, running the site full time.

Schachter's original focus on the individual user has never wavered, and it remains essential to the way del.icio.us works. But as more and more people started to use the site, something interesting happened: when aggregated, all those individual tags created a useful system for categorizing Web pages. On the surface, del.icio.us doesn't seem designed to do this, since each person makes his or her own tags, and there's no overarching authority to maintain order. But even with no one in charge, the product of all the individual decisions of del.icio.us's users is surprisingly well organized—and surprisingly intelligent. That is, if you do a search on del.icio.us for all the pages that are tagged with a particular word, you're likely to come up with a remarkably good—and well-rounded—selection of related Web sources. In other words, although del.icio.us didn't need lots of users to be useful, once it had lots of users, it became valuable in an entirely new way. Almost accidentally, it became an excellent tool for making sense of the Web.

What del.icio.us's users were creating—without necessarily knowing they were doing so—was what technology blogger Thomas Vander Wal has dubbed a "folksonomy," a flexible system of organization that emerges organically from the choices users make. We're all familiar with the alternative, the kind of rule-bound, top-down classification scheme that Internet theorist Clay Shirky calls "ontological" in nature. The Dewey decimal system is an example: every object is assigned its place in a hierarchical system of organization, and every object is defined as, ultimately, one thing: a book goes in one place in the library and nowhere else. In a folksonomy, by contrast, definitions are fuzzier. With del.icio.us, the same Web page has many different tags, which often aren't even related to one another, and no explicit rules are being followed. Web pages are therefore listed not in one place but in many places, and sometimes pages aren't quite where you might expect them to be. So folksonomies are messier than "ontologies" are.

What del.icio.us has shown, though, is that folksonomies' imperfections are outweighed by their benefits. In the first place, folksonomies are dynamic rather than static. A Web folksonomy thus allows us to reclassify content according to our changing interests. An academic paper that's interesting today might be equally interesting a decade from now—but why it's interesting, why people care about it, might be very different. A traditional categorization system has a hard time dealing with this: once the essence of an object is defined, it's supposed to be defined for good. In a folksonomy, the reclassification happens almost automatically—as people start tagging the paper with new, more relevant tags, for example. Web folksonomies are also better at capturing the multiple meanings and uses that a given site has, rather than constraining the possible range of meanings. It's useful, after all, to learn that many people have tagged stories about Mark Cuban "crazy," in addition to indicating everything else that's important about him. Finally, folksonomies are cheap. Imagine the labor and the time it would take to construct a traditional organizing system for all the pages on the Web, and then to maintain and update it. Then recognize that del.icio.us is producing a ceaselessly revised organizing system—at almost no cost.

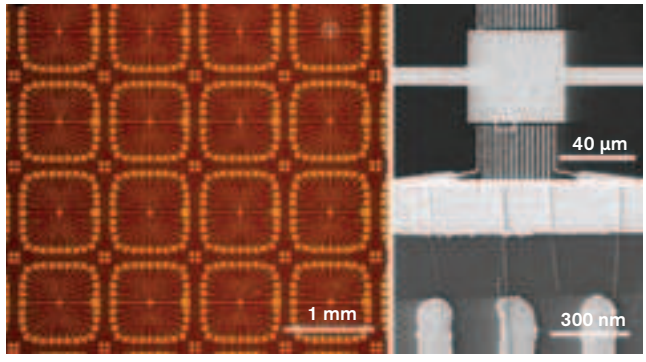
The real magic of folksonomies—and the reason sites like del.icio.us can create so much value with so little hired labor—is that they require no effort from users beyond their local work of tagging pages for themselves. It just happens that the by-product of that work is a very useful system for organizing information. This distinguishes del.icio.us from other high-profile Web 2.0 sites like Wikipedia and Digg, which people contribute to without reaping any obvious personal benefit.

Even with no overarching authority to maintain order, the product of all the individual decisions of del.icio.us's users is surprisingly well organized—and surprisingly intelligent.

Schachter thinks the fact that del.icio.us does not rely on the selflessness of its users makes it more robust than it might otherwise be. "I'm not a big believer in expecting a large number of people to act in an altruistic fashion," he says. "You want to rely on people to do what they do." The echoes of Adam Smith are unmistakable: del.icio.us is a system that, like a healthy market, turns individual self-interest into collective good.

Del.icio.us now has more than 300,000 registered users, and it generates as much traffic in a single day as it did in its entire first year. But even as tagging has become an industry buzzword that businesses are straining to associate themselves with, Schachter is confronting the fact that the vast majority of people on the Web don't tag at all—and probably have never even heard of tagging. So how does he expand his site's audience? "You have to solve a problem that people actually have," Schachter says. "But it's not always a problem that they know they have, so that's tricky." He remains more focused on the site's value to the individual than on its folksonomic aspects, because to him, helping individuals store and recall information is far more important than classifying the Web. And it may well be individual value that's most likely to keep del.icio.us growing.

Regardless of what happens, Schachter has already shown that out of the seeming chaos of hundreds of thousands of independent and eccentric judgments, order and wisdom can emerge. And if you think about del.icio.us in terms of his idea of making memory scalable, he's also helped create a rather remarkable social memory system, in which all of us are able to find more and better information than we would on our own. As Schachter puts it, "The one who stashes a page doesn't have to be the one who ends up recalling it. Del.icio.us is a storer of one's own attention. But it also means you can share it with others." And that ability will only become more valuable over time. "The better you understand the world, the better you'll do," Schachter says. "I really think that in the end, more understanding wins." TR



COURTESY OF SONG JIN

NANOTECHNOLOGY

Song Jin, 31

University of Wisconsin–Madison

Making nanowires get in line

Song Jin has developed a simple way to align nanowires, allowing researchers to easily incorporate them into useful devices such as biosensors. Jin compresses nanowires afloat on water until they're oriented in the same direction. He then transfers the aligned nanowires to another surface, on which he deposits electrodes using conventional lithography ***(see "The Future of Nanoelectronics, p. 26).***

To illustrate his method, Jin created an array of nanowire-based transistors (above left). Each cluster is a group of electrodes converging on a common electrode in the center (top right). Hairlike nanowires bridge the gaps between the electrodes (bottom right).

By outfitting the nanowires with molecules that bind to specific viruses or chemicals, researchers have demonstrated the value of his method for sensing applications: when a virus fastens onto a nanowire prepared this way, the wire's conductivity changes, just as applying a voltage changes the conductivity of a semiconductor in a transistor. Each nanowire is sensitive enough to register a lone virus particle. KEVIN BULLIS



INTERNET

Sumeet Singh, 31

Cisco

Faster defenses against computer viruses

Problem: Current antivirus systems rely on humans: when a network attack comes to light, security analysts begin looking for a string of bytes—a "signature"—that uniquely identifies the malicious program. The signature must be downloaded (often automatically) before software can identify and block attacks. But the whole process takes hours—or days—while attacks can infect up to 55 million computers *per second.*

Solution: Sumeet Singh has completely automated worm and virus detection, putting defenders on the same footing as attackers. As a graduate student at the University of California, San Diego, Singh realized that worms and viruses move through a network differently from normal traffic: malicious code strives to reproduce and propagate itself rather than simply to travel from point A to point B. So he created software tools that scan for snippets of data that exhibit such behavior.

Incorporated into a network router or switch, Singh's software can identify malicious code when it first enters a network and generate "vaccines" to combat its spread. In June 2004, Singh cofounded NetSift with his PhD advisor, computer science professor George Varghese, to commercialize his technology. Cisco purchased NetSift just a year later; Singh has since led the integration of his techniques into Cisco routers and switches. He hopes that this technology, able to scan more than 20 gigabits of data per second, will eventually stop viruses and worms as soon as they pop up. *—Daniel Turner*



HARDWARE

Ling Liao, 33

Intel

Lighting up computers

Within the next few years, computer chips will process data so rapidly that the wires carrying information between them will have difficulty keeping up. One possible solution is to transport the data using laser beams that blink on and off billions of times a second. Ling Liao, of Intel's Photonics Technology Lab, is bringing us closer to that goal by figuring out how to build key optical components from the same silicon used to make the rest of a computer chip. That would make integration simpler and bring down costs.

But silicon is normally a poor optical material; it's par-



SOFTWARE

Paris Smaragdis, 32

Mitsubishi Electric Research Lab

Teaching machines to listen

Computer scientist Paris Smaragdis is building some of the world's most advanced "machine listening" systems—software that uses sound to locate people moving through rooms, monitor machinery for impending breakdowns, or activate traffic cameras to record accidents. It's work you have to hear to understand. To listen to a podcast about it, go to www.technologyreview.com/TR35/parissmaragdis.aspx.

ticularly hard to get silicon to modulate light—that is, to induce the blinking effect that encodes data. More exotic materials can make light fluctuate in response to a changing electric field, but silicon resists that approach. Liao found that if she put a thin layer of silicon dioxide between two slabs of silicon, she could quickly make electrons accumulate on both silicon surfaces, and remove them quickly as well. That alters any light waves that pass through the silicon, making them either dimmer or brighter. By building up and then releasing the charges using an alternating voltage, she can modulate light at 10 gigabits per second, and she's working on ever faster speeds. It may be a decade before her device finds its way into your computer, but eventually optical connections may be able to handle speeds hundreds of times faster than those seen in today's PCs. *—Neil Savage*



BIOTECHNOLOGY

Liam Paninski, 28

Columbia University

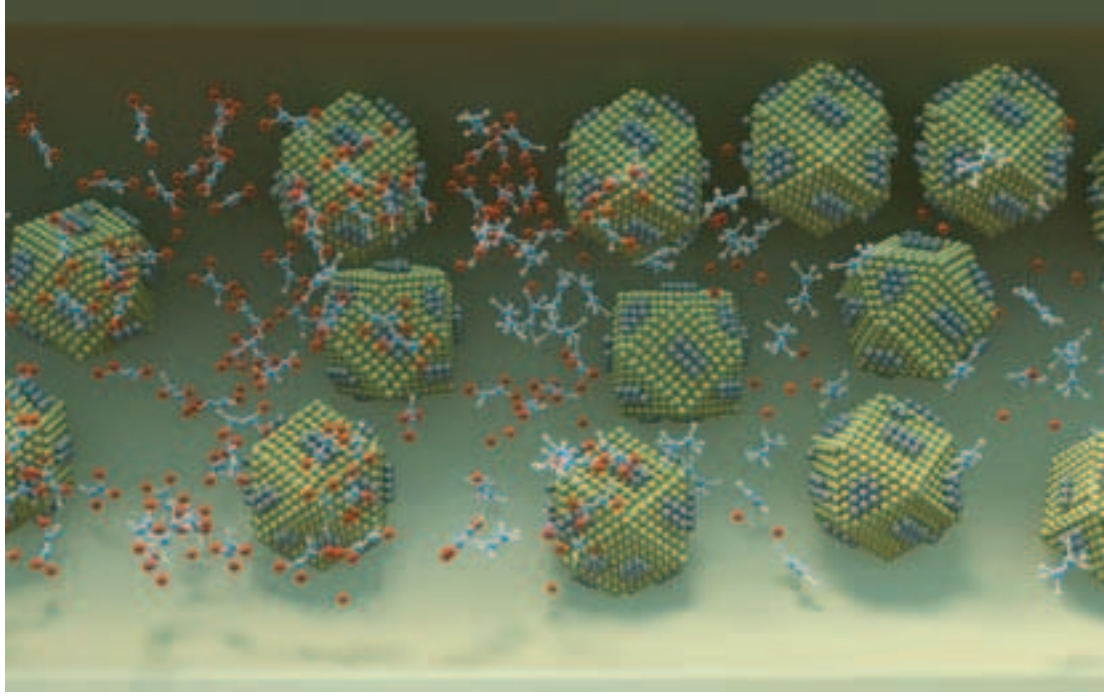
Decoding brain signals

Today, researchers can record and interpret brain signals with such sophistication that "mind reading" is close to becoming a reality. One of the young leaders in the field is computational neuroscientist Liam Paninski, who uses statistics to decipher electrical signals from the brain.

Because neurons fire in complex patterns, it's tricky to identify which neurons encode which actions and how stimuli provoke them. Paninski creates mathematical models to make sense of those patterns. As an undergraduate at Brown University, he developed an algorithm that decodes arm-movement commands from the brain. Equipped with this neural code, Brown neuroscientist John Donoghue developed an implant that lets paralyzed people use their minds to control a robotic arm, manipulate a cursor, or play video games *(see "Implanting Hope," March 2005)*.

Now a professor at Columbia, Paninski is using his statistical methods to decode vision. In the future, he hopes, implanted "video cards" may

CHRISTOPHER CHURCHILL



PURIFYING POLLUTION
As contaminated groundwater flows through hollow-fiber filters, toxic trichloroethylene (TCE) molecules stick to gold-and-palladium nanoparticles. The particles catalyze the transformation of TCE into harmless ethane gas and dissolved chlorine.

restore sight to the blind by translating digital images into neural patterns. He's also exploring ways to treat epilepsy; as researchers decode neural signals more precisely, Paninski hopes to one day create a complete map of normal brain activity. Using the map, researchers could detect deviations such as epileptic events. Paninski envisions a warning device that will recognize abnormal events early, so that patients can take drugs to stave off a seizure—or at least get to a safe place before it begins. *—Jennifer Chu*



INTERNET

Ben Zhao, 30

University of California, Santa Barbara

Perfecting peer-to-peer networks

Ben Zhao wants to improve the Internet by letting new networks piggyback on top of it.

Zhao creates structured overlay networks. These peer-to-peer networks are like the ones file-sharing services use, routing data directly between individual users over the Internet. But instead of allowing any computer in the network to talk to any other, structured overlays have strict rules about which machines may talk to which. This allows them to route data more efficiently and to detect and sidestep failures more quickly. "Everything is about resiliency and recovery and robustness," Zhao says.

As a graduate student at the University of California, Berkeley, Zhao wrote Tapestry, a series of networking protocols that was one of the first structured overlay networks. Some of his Berkeley colleagues built an application called OceanStore that uses Tapestry to provide cheap, reliable, global-scale data storage. Since then, Zhao and others have developed a host of programs that take advantage of Tapestry.

Now an assistant professor at UC Santa Barbara, Zhao is working to make structured overlay networks more secure. With companies such as Microsoft interested in the technology, his success could mean practical networks that manage and heal themselves. *—Erika Jonietz*

BRYAN CHRISTIE DESIGN

NANOTECHNOLOGY

Michael Wong, 34

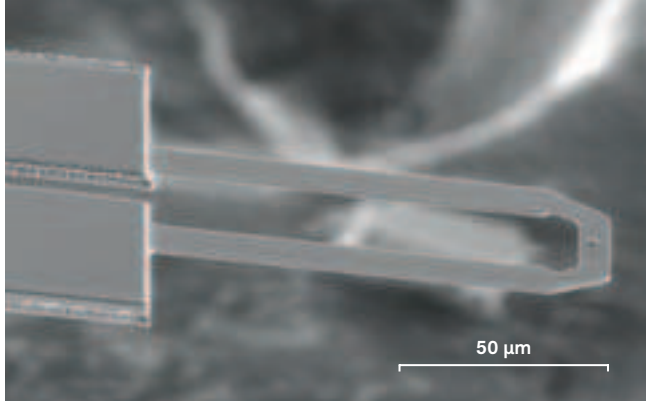
Rice University

Cleaning up with nanoparticles

With some 300,000 hazardous-waste sites scattered across the United States, cleaning up contaminated soil and groundwater is a daunting challenge. Chemical engineer Michael Wong is taking on toxic waste with tiny particles that can break down organic pollutants more quickly, and perhaps less expensively, than existing technologies.

Each particle measures just four nanometers across and consists of a gold granule spotted with palladium. The nanoparticles' high surface-area-to-volume ratio enables them to split chemicals faster than larger particles could, but their real advantage lies in their unique combination of metals. Palladium on its own does an adequate job of breaking down toxic chemicals such as trichloroethylene (TCE), an industrial degreaser that is linked to cancer and contaminates 60 percent of sites overseen by the U.S. Environmental Protection Agency's Superfund project. But spotting the palladium on gold has a synergistic effect: the combination particles catalyze the removal of chlorine atoms from TCE molecules 100 times as fast as palladium particles alone.

Wong is already developing ways to incorporate his nanoparticles into filters for treating contaminated groundwater. To keep the particles in place, he has designed a method of growing them directly on the inner walls of hollow fiber tubes. He plans to test the system in the field this fall. ALEXANDRA GOHO



TINY HEATER **Heated silicon tips like this one can act as "soldering irons" to create nanoscale features in items like circuits and biological scaffolds.**

NANOTECHNOLOGY

William King, 32

Georgia Institute of Technology

The world's smallest soldering iron

What can you do with a nano-sized soldering iron? William King has a few ideas.

As a graduate student, King was invited to join the Millipede project at IBM's Zürich Laboratory. The project's experimental data-storage device uses a cantilevered silicon bar with a tip just 20 nanometers wide to melt tiny divots into plastic, "writing" data at 50 times the density of today's best hard drives. By modeling the choppy flow of heat through the narrow silicon bars, King helped IBM engineers control it precisely—and so use a single tip to read, write, and even erase data.

Since joining the Georgia Tech faculty in 2002, King has incorporated similar tips into nano soldering irons for making items as diverse as electronic circuits and tissue-engineering scaffolds. By cycling the tips to 1,200 °C and back to room temperature millions of times a second, King releases the "solder"—be it a semiconductor, an insulator, or a biocompatible polymer—far more precisely and quickly than researchers who deposit materials by lowering and raising silicon tips. *—Peter Fairley*

INTERNET

Jason Fried, 32

37signals

Keeping online collaboration simple

37signals builds aggressively simple Web-based collaboration tools that help people manage everything from family to-do lists to big corporate projects. Hundreds of companies are using Ruby on Rails, the open-source software toolkit that the firm created, to quickly develop their own online applications. Jason Fried, the founder and president of the seven-person firm, is fond of saying, "It's better to tell a short story well than a long one poorly." In that spirit:

"Jason is immune to dogma and has much to teach. In 37signals, he has built an elegant company with elegant products based on the idea that less is more."

—Jeff Bezos, CEO, Amazon.com, and the first outside investor in 37signals

SOFTWARE

Jane McGonigal, 28

42 Entertainment

Designing games with new realities

The pay phone rings. This much you know: in the 26th century, a young girl's personality was uploaded into an artificial intelligence called Melissa aboard a military starship, which was then thrown back through time to your own year, 2004. Now the starship's crew is dead; Melissa survives, damaged and stranded on the Internet server of a beekeeper in California's Napa Valley. From that beekeeper's website, ILoveBees.com, you gleaned this phone's GPS coördinates. You cup the receiver to your ear as Melissa speaks …

If this seems familiar, you were probably among the 600,000 active players of I Love Bees in 2004. To date, it remains the most widely played "alternate-reality game." Jane McGonigal, who recently completed her PhD in performance studies at the University of California, Berkeley, was tapped to become one of the game's four "puppet masters" after she began working with 42 Entertainment, a company in Emeryville, CA, that creates entertainment-based marketing campaigns and original content. Microsoft had hired the company to promote Halo 2, the video game it was about to introduce, by creating a massively multiplayer alternate-reality game. McGonigal designed the real-world "missions" that took advantage of and shaped the way the players organized themselves. Creating and engaging this worldwide community helped make I Love Bees so successful. McGonigal argues that alternate-reality games use network technologies—e-mail, websites, Internet chat rooms, text messages, and phone calls—to construct new types of communities whose "collective intelligence" lets them solve problems no member could solve alone. In 2005, she and the I Love Bees team won the Game Developers Choice Awards' Innovation Award and the International Academy of Digital Arts and Sciences' Webby Award.

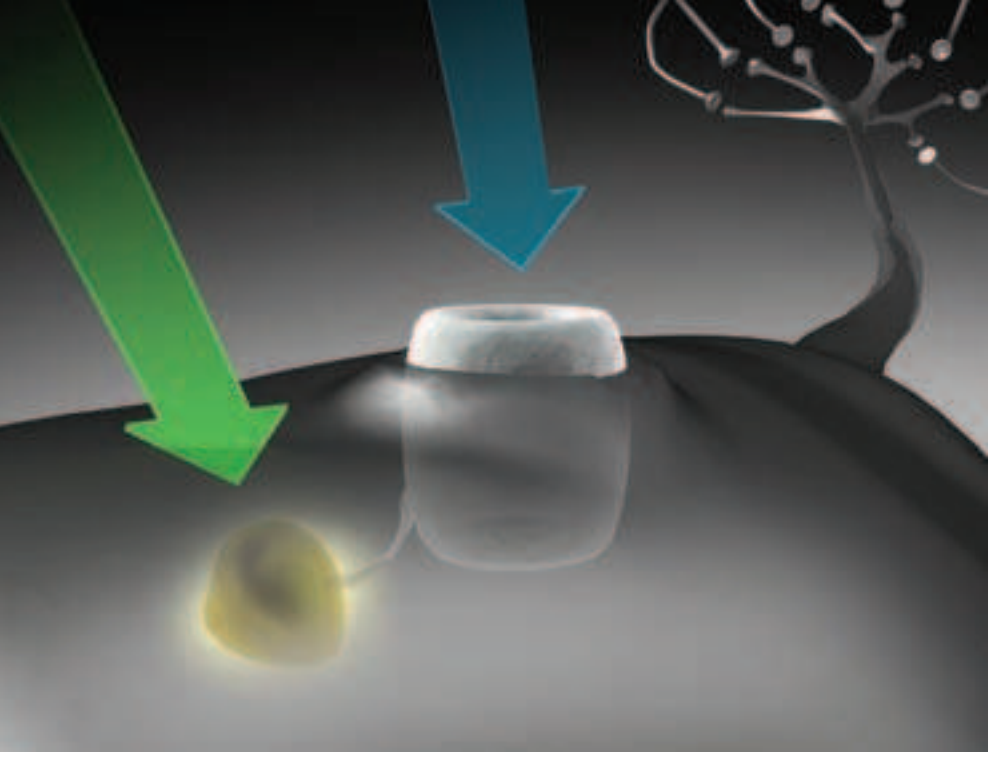
McGonigal argues that alternate-reality games use network technologies to construct new types of communities.

McGonigal has continued working with 42 Entertainment. In 2005 she developed Tombstone Hold 'Em, part of a 2005 promotion for Activision's game Gun; crowds congregated in historic cemeteries to play poker using tombstones instead of cards. Such novel uses of public spaces are another way she engages players. Her own work as a game designer is fed by watching players interpret the missions she designs: "They always think of far more interesting things than anything I could imagine." **MARK WILLIAMS**

COURTESY OF WILLIAM KING



POLLY BECKER



LIGHT STIMULATION
Edward Boyden created a new protein that allows neuroscientists, for the first time, to find specific types of neurons and activate them on cue. Shining green light on cells making the protein causes them to glow yellow; blue light causes the neurons to fire within milliseconds.

BIOTECHNOLOGY

Edward Boyden, 27

Stanford University

Artificially firing neurons

Even in the hypertechie milieux of MIT and Stanford science departments, Edward Boyden stands out, bubbling with brilliance, energy, infectious enthusiasms, imaginative approaches to impossibly ambitious projects—and through it all, at his most earnest, with a vibrant sense of play. At MIT, he got a bachelor's in physics and bachelor's and master's in electrical engineering and computer science, all with a perfect grade-point average—and by the age of 19.

Fascination with computing led him to neurobiology. "The brain is a three-dimensional mass of densely wired tissue," he says. "It's kind of the ultimate computer." He landed at Stanford, where he got his doctorate in 2005, aged 26. There he created an ingenious new technology for analyzing and even controlling any neural circuit, including those in the cerebral cortex—important in sensation, action, thought, emotion, memory.

In the science of the cortex, perhaps the toughest problem is to determine how neurons interact with their near neighbors. The cortex has some 20 billion neurons, which have many different functions. For years, neurobiologists have known various ways to measure the outputs of individual neurons when they fire. Yet no method had been found to control inputs, to find and deliberately activate cells of one particular type.

Boyden's technology—an elegant, tricky piece of genetic engineering—gives scientists exactly that. It begins with a curious protein called Channelrhodopsin-2, or ChR2. This protein normally sits in the cell membrane of a green algae, and when exposed to blue light it changes the cell's electrical state. Working with Stanford colleagues and the German researchers who isolated the protein and the gene that encodes it, Boyden linked the gene for ChR2 to the gene for a protein that fluoresces when hit by green light, creating a single, novel protein. The researchers inserted the gene for this new protein into rat neurons. Under green light, the cells that made the combination protein glowed; blue light caused the neurons to fire. Boyden had thus invented a precise, reliable neural switching system operating at thousandths of a second—the speed at which neurons naturally interact.

He has since added genetic elements that control just which type of neuron makes the new protein. Introduced into, say, a mouse's brain, the protein could highlight individual types of neurons and allow researchers to study their functions.

One possible use, Boyden says, is to analyze the neural circuits that perform particular types of "computation," such as decision-making. Clinical applications are potentially huge: delivered to the brain and activated by implanted optical fibers, the protein could give doctors the power to activate neurons with selected functions. That could give rise to radical new medical technologies to treat brain disorders such as Parkinson's disease or even some types of blindness, Boyden says. He believes that activating the right neurons could change mental and emotional states—perhaps curing prolonged, profound depression. More grandly, he projects enhancements of human mental capabilities, even the control of behavior.

"We can maybe apply some simple versions of the technology to solving urgent questions of today," Boyden says. "There's a lot of synergy between that and the technology that we use to do very, very hard things, such as addressing psychiatric disorders, confronting questions of consciousness, making brain-machine interfaces—and on the way to climbing those mountains, we can have a lot of little picnics!" **HORACE FREELAND JUDSON**

BRYAN CHRISTIE DESIGN



TELECOM

Apostolos Argyris, 30

University of Athens

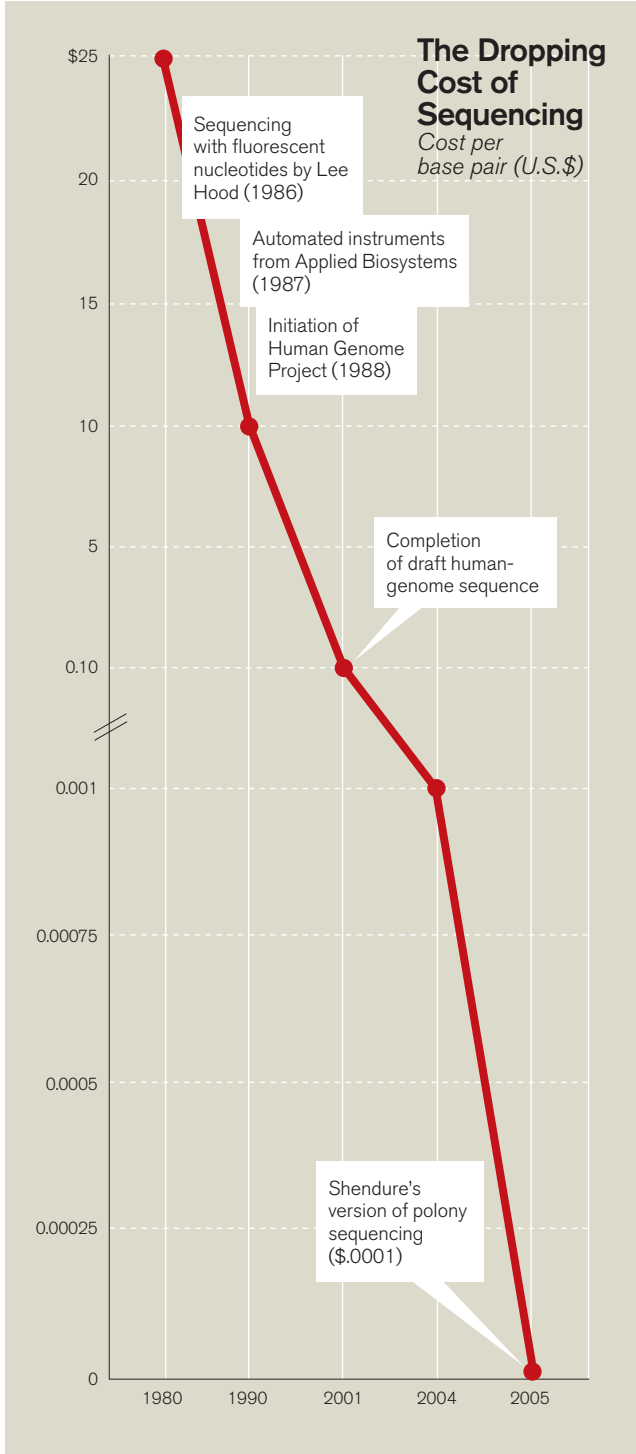
Disguising data as noise

Apostolos Argyris has joined theoretical mathematics with solid-state physics to demonstrate a novel, nearly unbreakable encryption method. As a graduate student at the University of Athens, the Thessaloníki native implemented the first long-distance demonstration of "chaotic synchronization": using a pair of laser diodes, amplifiers, a mirror, and more than 120 kilometers of underground fiber, he disguised a message as white noise and still retrieved it clearly on the other end.

The feat is a demonstration of the "butterfly effect," the founding tenet of chaos theory. The theory holds that in sufficiently complex systems, even a slight adjustment of initial variables will produce a dramatically different result; conversely, if you can replicate input conditions precisely, you should be able to replicate the output, even if that output appears random at first glance.

Argyris applied this principle by combining a digital message with a chaotic, rapidly fluctuating laser signal; the chaotic signal's irregular shape masks the message and allows it to evade standard eavesdropping methods. An identically generated chaotic signal on the receiving end cancels out the first, leaving only the original data.

The technique currently delivers data at one gigabit per second (good enough for voice and video encryption). Argyris hopes to raise that to 10 gigabits per second by 2009. He doesn't see chaotic encryption replacing software encryption, but it could soon offer an extra layer of protection for the most sensitive communications. *—Sam M. Williams*



BIOTECHNOLOGY

Jay Shendure, 31

Harvard Medical School

The $1,000 genome

Biotechnologist and medical student Jay Shendure is revolutionizing genetics with a new way to sequence DNA. In 2005, he used off-the-shelf parts to determine the order of all the DNA bases in a bacterial genome, at 20 times the speed and one-ninth the cost of traditional DNA sequencing. Shendure is now working to make the process even more efficient; by 2015, he says, it may enable biologists to sequence a person's genome for just $1,000.

The technique builds on polony sequencing, a method developed in George Church's lab at Harvard. Shendure spreads millions of tiny beads on a glass slide, each attached to a small DNA fragment. He then adds fluorescently labeled DNA bases. The bases bind to short, complementary DNA sequences, and a standard fluorescence microscope records which base is at each position on a fragment.

Shendure next plans to use the technique to sequence the genome of a lung tumor in order to identify the genetic mutations that caused it. EMILY SINGER

MARK OSTOW

BIOTECHNOLOGY

Alice Ting, 31

MIT

Lighting cellular movies

Alice Ting's movies won't fill any theaters, but they are breaking ground in using what's called "fluorescence imaging" to reveal the minute inner workings of cells in unprecedented cinematic detail.

To make her biology-in-action movies, Ting, an assistant professor of chemistry at MIT, needed a bright and efficient light source. So her lab developed a way to, effectively, glue superbright fluorescent "tags" directly to proteins of interest. The standard way to make proteins glow is to use green fluorescent protein (GFP), originally isolated from jellyfish, and cousins that fluoresce in different colors. But these proteins produce relatively dim light, making it difficult to see single molecules or in vivo processes. They also have to be genetically fused to the proteins being studied; this can alter the proteins' behavior and prevent them from freely moving around and into cells. In contrast, Ting used quantum-dot tags that are up to 100 times brighter than GFP and interfere less with the observed proteins.

"Alice Ting is a true innovator and is one of the best chemists of her generation," says Timothy Swager, chair of MIT's chemistry department.

Other labs had labe led proteins with quantum dots—nanocrystals that fluoresce in different colors depending on their size—but attached them with the help of bulky antibodies. Ting's lab did away with these clunky connectors and, at the same time, created far more secure ones, fusing small protein "linkers" to both the quantum dots and the proteins of interest. Ting then used an enzyme to join her two linkers, and voilà—she could observe a living cell in action. Nor is the linking system limited to quantum dots: it can be used for any tag.

"Alice Ting is a true innovator and is one of the best chemists of her generation," says Timothy Swager, chair of MIT's chemistry department. "Scores of research groups around the world are already applying her methods."

One of Ting's latest projects is to fluorescently image the junction between nerve cells, illuminating a biochemical process that appears to play a key role in learning and memory. So it may be possible one day to see an actual film of how a brain learns. "Mammalian cells are so beautiful and funky," says Ting—with the appreciation of a true director. **JON COHEN**

COURTESY OF CHRISTOPHER VOIGT; PETER BYRON (MALIAKAL)



NANOTECHNOLOGY

Ashok Maliakal, 31

Lucent Technologies' Bell Laboratories

The floppy screen

Plastic semiconductors have already found their way into a number of electronic gadgets, providing displays that are bright and easy to read even in direct sunlight. But efforts to make larger plastic displays—say, a computer monitor that rolls up and slides into your bag—have hit a roadblock: the electronic circuitry that drives their colorful pixels consumes too much power, and existing materials don't print well onto large sheets of plastic.

Working at Bell Laboratories in Murray Hill, NJ, Ashok Maliakal has homed in on this problem. One major challenge, he says, was to improve the circuits' gate dielectric—the insulating layer that enables their transistors to switch properly from "on" to "off."

Maliakal designed a completely new dielectric material comprising nanoparticles of titanium dioxide encapsulated in polymer shells. The titanium dioxide boosts the material's insulating properties, while the polymer makes it easy to print. Prototype circuits made with the material operate at one-third the voltage of those made with the polymer alone. That could mean displays that consume a lot less power. If Maliakal can incorporate his material into a mass-printing process, a new generation of flexible displays will be ready to roll. *—Alexandra Goho*

BIOTECHNOLOGY

Christopher Voigt, 30

University of California, San Francisco

A vision in bacteria

Synthetic biologist Christopher Voigt has created an unusual image: the Virgin Mary on a lawn of *E. coli* (below).



In turning microbes into a "photographic" medium, Voigt and his team have illustrated his approach to synthetic biology: creating genetic parts that can be used interchangeably to achieve different results. They hooked a light receptor from blue-green algae to a protein that normally controls *E. coli* genes' response to the cell's surroundings. They then swapped one of these genes for one that turns a certain chemical black. The finished bacterium turned black in the dark; by holding a stencil between a petri dish and a light source, the researchers could impose an image onto the bacteria.

Though Voigt says the bacteria are just a "toy technology," he is using the same precepts to develop parts for more-complex organisms, such as bacteria that spin spider silk or target and kill cancer cells. *—Emily Singer*



TELECOM

Prithwish Basu, 31

BBN Technologies

Networking unplugged

Sending and receiving data can be difficult for people on the move, especially when they travel out of the range of a stationary wireless base. Enter "ad hoc networks," in which radios communicate directly with each other—no central base station required. Prithwish Basu, a scientist at BBN Technologies in Cambridge, MA, has developed algorithms that dramatically reduce the chance that a wireless network will drop connections or fail, all while decreasing the energy consumed by battery-powered radios. The algorithms will work for networks of sensors, for people carrying mobile computers, or even for groups of robots with onboard radios. The U.S. Defense Department is interested in testing these designs as a way to help keep soldiers in touch on the battlefield, but Basu's true passion is finding ways to incorporate ad hoc networks into everyday life.

***TR*: What are ad hoc networks useful for?**

Basu: To keep mobile soldiers in contact with one another and with command, ad hoc networking is the most attractive solution. On the commercial end, people were a little skeptical a few years ago. But sensor networks have really taken off recently. People are buying sensors and deploying them to monitor different phenomena: traffic, pollution, wildlife habitats, train schedules. So I've been pushing my company to look more into commercial aspects.

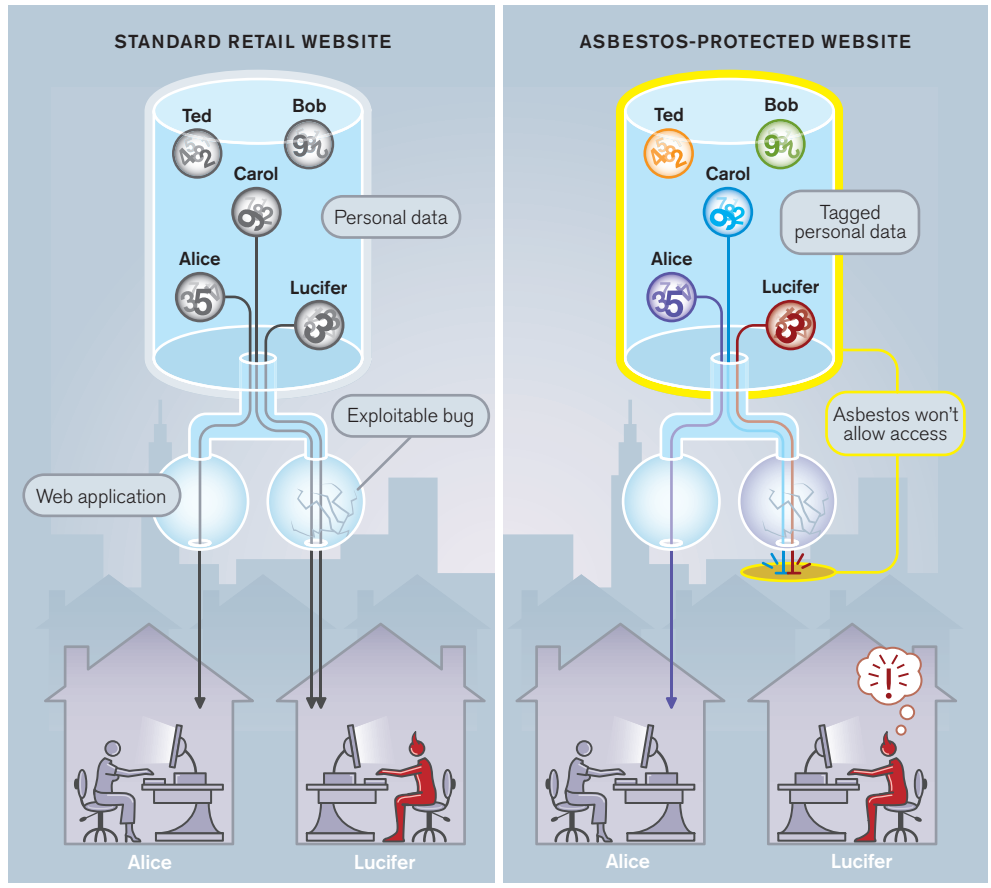
What nonmilitary applications have you considered?

When I was a graduate student at Boston University, I proposed networking parking meters. You put wireless transmitters on each parking meter in a city; then you add a sensor that can tell whether there is a car in that spot. If my car also has a transmitter and I am entering Harvard Square from one direction, I can ask my user interface for a parking space near the law school. My car will query the nearest meter, and if that one's full, it will propagate the query until it finds a free spot, and then even reserves it, if possible. The network could also allow parking police to determine violators almost instantly. A number of undergraduates are now implementing a network based on these principles.

Could the mobile-robot networks you've developed be useful in daily life?

If you have a group of robots running the appropriate algorithms, you can program them to perform any collaborative task. Suppose you have a network of Roombas [robot vacuums] and you want to clean a ... hotel floor. If one room is dustier, one Roomba would send a message to three others: "Hey, this space is very dirty, so please come over." If your protocols are working correctly, you'll get a distribution of [robots] that follows the dust pattern. Robots connected this way could also help with relief operations in large disaster sites. **LAUREN GRAVITZ**

POLLY BECKER



HOW ASBESTOS WORKS
Left: Legitimate users can retrieve their data, but a malicious user can also exploit bugs in the website's software to steal others' data. Right: Data is tagged to indicate the user's identity; if a user requests data that isn't hers, Asbestos blocks its transmission, regardless of flaws in the website.

SOFTWARE

Eddie Kohler, 33

University of California, Los Angeles

A better operating system

Operating systems are the software foundation for all computers, from laptops to servers—but most were designed decades ago, without Internet security in mind. Small flaws in the operating system or software on, say, a bank's server could compromise millions of dollars' worth of sensitive data. To make such information more secure, computer scientist Eddie Kohler and his team designed Asbestos, an operating system that keeps private data from falling into the wrong hands even when other software on a computer has failed.

Asbestos keeps personal data secure by "tagging" it with information about which programs or users can access it. Usually, this sort of tagging requires a large amount of memory, but Kohler has structured the tag data to use minimal system resources. Initial tests have been promising, and Kohler hopes that within a few years, Asbestos will be an alternative to server operating systems such as Linux and Windows. *—Kate Greene*

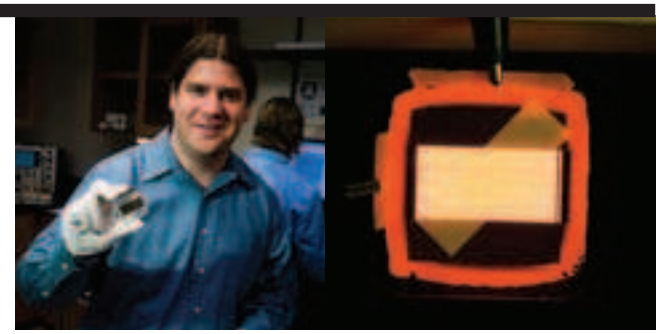
HARDWARE

Seth Coe-Sullivan, 29

QD Vision

Making screens crystal clear

As a graduate student at MIT, Seth Coe-Sullivan created a possible way to make amazingly bright and colorful displays using quantum dots, tiny semiconductor crystals that emit specific colors of light when energized. Researchers had made light-emitting devices out of quantum dots before, but Coe-Sullivan improved their efficiency by developing a technique that produces a uniform, ultrathin layer of the dots between two flat electrodes. He then cofounded QD Vision in Watertown, MA, with the goal of arranging quantum dots into pixels to create full-color, flat-panel displays for cell phones, laptops, and televisions. As chief technology officer, Coe-Sullivan has already led the fabrication of small monochromatic displays as well as the development of a process that will lead to full-color versions. These screens will produce brighter images and more saturated colors than conventional displays—while reducing both component cost and power consumption by half. They could appear in cell phones by 2009. KEVIN BULLIS



COE-SULLIVAN holds a prototype quantum-dot display; plugged in (above right), the display shows off its bright pixels.

PORTER GIFFORD (COE-SULLIVAN); FUNNELINC.COM (KOHLER)

TR35



HARDWARE

Ram K. Krishnamurthy, 33

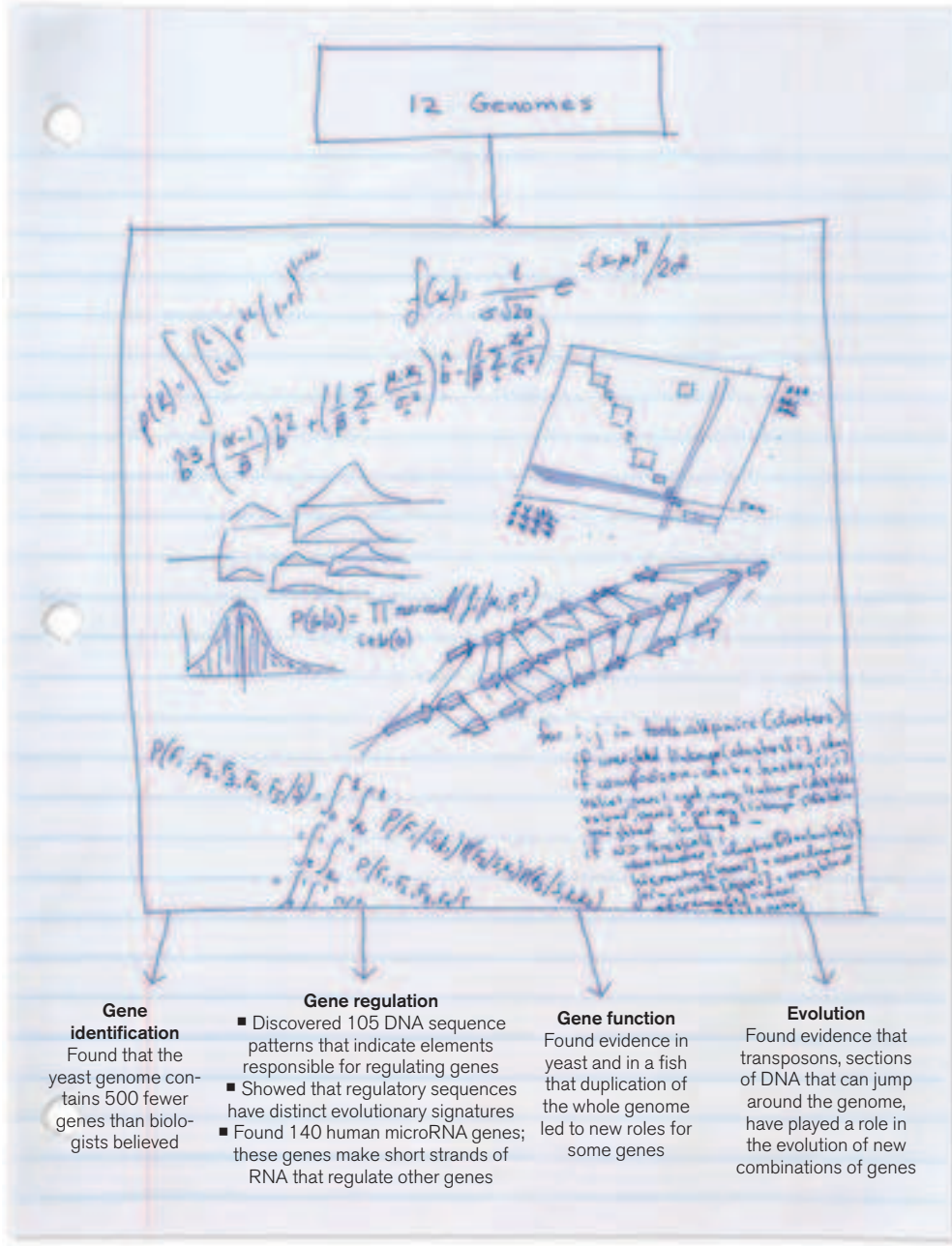
Intel

Cooler computers

Problem: As chip makers increase computing power by packing more and more transistors into the same space, they could end up with chips that become too hot to operate. In fact, if the pace continues, by 2010 computer chips will theoretically generate as much heat per square centimeter as a nuclear reactor.

Solution: By carefully plotting chip circuit paths, Intel engineer Ram Krishnamurthy has minimized energy leakage and improved performance; his prototype circuits run five times as fast as those in today's PCs but consume 20 to 25 percent as much power. In less than a decade Krishnamurthy has amassed 53 U.S. patents relating to circuit design. Intel, IBM, and Hewlett-Packard are already incorporating aspects of his work into advanced circuits that will lead to servers requiring no costly cooling systems, as well as to laptops with longer battery life. And if PCs soon run at a cool 10 gigahertz, it may be thanks largely to Krishnamurthy's work.

—Daniel Turner



BIOTECHNOLOGY

Manolis Kellis, 29

MIT

Understanding genomes

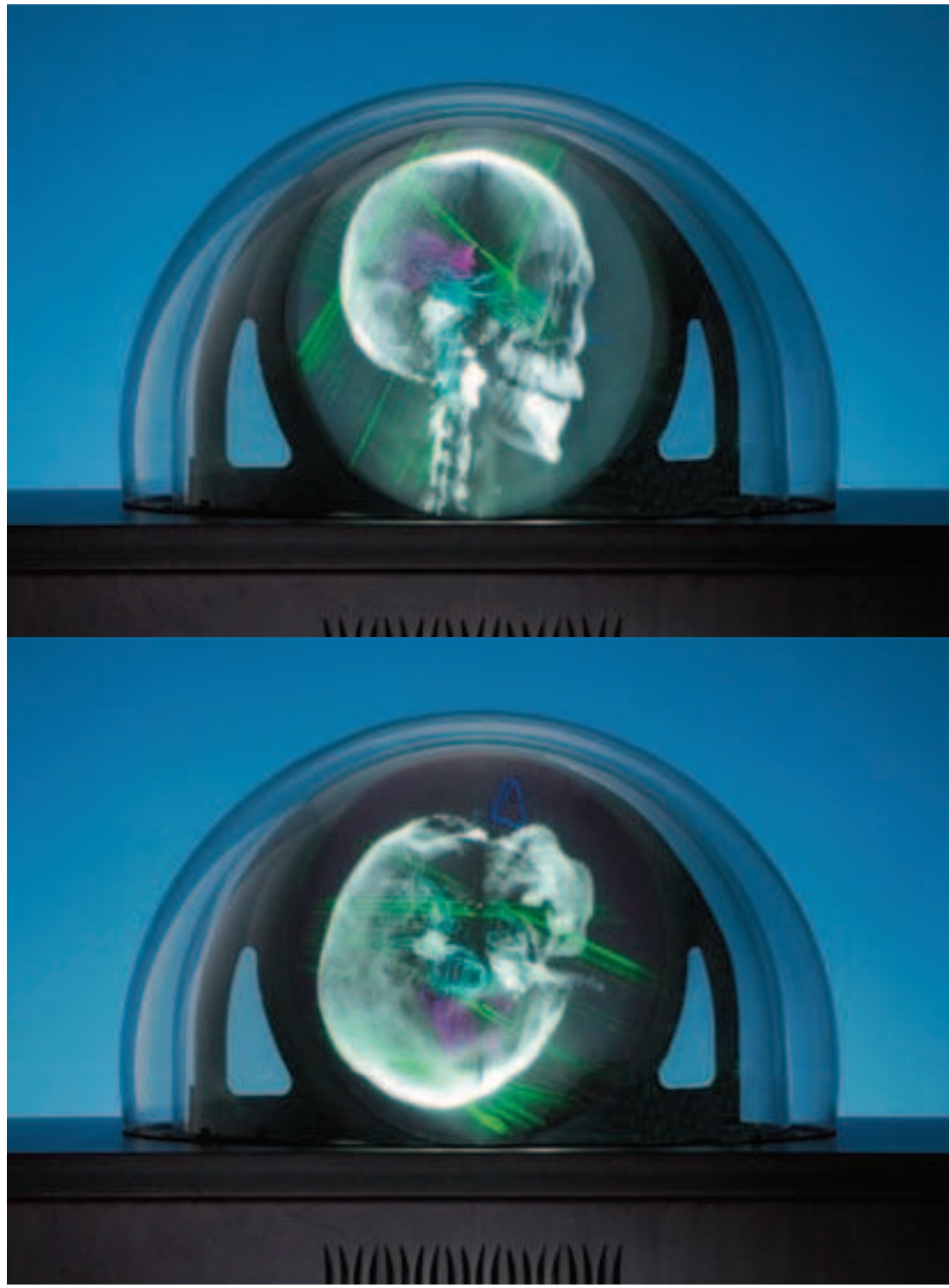
Manolis Kellis develops algorithms and techniques for analyzing the entire genomes of different species, the better to understand those genomes. Kellis began his PhD work with little knowledge of biology: his undergraduate degree is in computer science. For his thesis, he compared the genomes of four yeast species to identify all the genes and regulatory sequences in one of them—a project he's glad no one told him was believed to be impossible. Comparing the genomes of multiple closely related species has proved to be a powerful new tool for finding genes and the sequences that regulate them, and for learning about how genomes evolve ***(see "Finding Evolution's Signatures," p. 28).*** **After validating his methods in yeast, Kellis has moved to the human genome, which he has so far compared with those of the mouse, rat, and dog. His work is providing an intimate understanding of the human genome that may give drug developers new points of entry in their attempts to combat viruses and other causes of disease.** KATHERINE BOURZAC

SOFTWARE

Joshua Napoli, 28

Actuality Systems

Higher-resolution 3-D displays



Before treating a tumor with radiation, an oncologist must decide how to direct the radiation beams so as to minimize damage to surrounding tissues without compromising efficacy. That kind of planning may soon become more accurate, thanks to true 3-D displays whose software Joshua Napoli helped pioneer.

The images at right show different perspectives on the same plan for treating a brain tumor with radiation: red marks the tumor site, blue marks critical structures such as the brain stem (which must receive as little radiation as possible), and green marks the proposed path of radiation beams. The images, 25 centimeters in diameter, are projected inside a somewhat larger dome; this "volumetric display" is made by Actuality Systems of Bedford, MA, where Napoli is head of software development. Napoli's software breaks up 3-D models generated by a computer into hundreds of frames that are projected onto spinning panels inside the dome, making a smooth, interactive image.

The software has produced the highest-resolution volumetric 3-D displays in the world, Napoli says. Along with doctors at three hospitals, Actuality is studying whether radiation plans made using its displays are superior to those made using traditional monitors. Eventually, doctors could use the 3-D displays to view most types of medical scans. Already, petroleum companies are using them to help visualize oil and gas deposits, and pharmaceutical researchers are using them to help picture how potential drugs interact with their targets. One of the biggest challenges, Napoli says, has been engineering the underlying graphics-processing software to work with real 3-D displays; displaying 3-D images this way requires a computer to process about 50 times as many picture elements as it would if the images were displayed on flat screens. *—David Talbot*

CHRISTOPHER HARTING

TR35

HUMANITARIAN OF THE YEAR

Christina Galitsky, 33

Lawrence Berkeley National Laboratory

Simple technologies save energy and lives

By Douglas McGray

Back in graduate school, Christina Galitsky could boil her life's work down into something like the title of a journal article: "The reversibility of proteins absorbing onto a surface," she says. But since she dropped off the PhD track and, later, took a job up the hill at Lawrence Berkeley National Laboratory, the question "What do you do?" has turned into a stumper. "I guess now I say, I try and work on … sort of innovative solutions to … wait, what do I say?" she says with a laugh.

Officially, Galitsky spends about two-thirds of her time developing tools to help companies diagnose energy inefficiencies and find new technologies that conserve power without sabotaging profits. But a glance around her office suggests that a host of other problems occupy her mind. On the floor lies an aluminum contraption, an efficient cookstove designed to fight deforestation in the poor world; she and her colleagues believe it might also keep refugee women in Darfur, Sudan, closer to their camps and out of the path of sexual assault. Later, she'll don a rust-stained lab coat and check on her students, who are testing a low-cost scheme to filter arsenic from the drinking water in Bangladesh.

"I'm involved in a crazy range of things," she admits. "But it would be hard to work on one thing all day long, five days a week."

When Galitsky left the chemical-engineering program at the University of California, Berkeley, with a master's in 1999, she found work testing the quality of California's surface waters. Quickly, she recognized that much of the contamination she encountered came from energy-related sources, such as the power industry. Eager to fight pollution rather than just measure it, she joined Berkeley Lab in 2001. There, she began diagnosing energy waste in nearly a dozen industries, from concrete to beer.

A couple of years later, when the California Energy Commission put up seed money for research into energy efficiency, she got more ambitious. Technologies such as occupant-sensing ventilation systems can help businesses conserve energy, and they often pay for themselves in just two or three years. But traditionally, business owners have had to discover those technologies and determine the costs and benefits by themselves—a huge barrier to adoption. Galitsky and her colleagues decided to test a new approach with California's wineries, offering them a system that would make it painless to spot their energy waste and find cost-effective ways to do better. (The wine industry requires huge amounts of power: 400 gigawatt-hours—enough to power nearly 60,000 homes—each year in California alone, and most of that during the summer and fall, when conservation matters most.)

Galitsky and her colleagues partnered with Fetzer, a large California winery, and started collecting data. It was tricky. In some industries, managers put power meters all over their plants, so they know how much energy each step of the manufacturing process demands. Wineries, however, tend to install just one meter for the whole operation. So Galitsky tallied everything from the number of grapes crushed to the sizes of Fetzer's refrigeration tanks and pieced the data into rough estimates of the power used at each stage of the winemaking process. Then she and her team surveyed wineries around the globe to identify the most energy-efficient technologies employed at each stage. The result is a tool called BEST-Winery, based on Microsoft Excel. It poses a series of questions, then spits out a score that compares the winery under review with a hypothetical winery of the same size and scale that uses the industry's best conservation technologies.

Other systems for measuring energy efficiency stop there. But BEST-Winery suggests more than 100 conservation technologies and runs a cost-benefit analysis for each one—a significant innovation for this kind of tool. Winery owners can mix and match different technologies and find comprehensive approaches that fit their budgets.

The state of California presented an award for energy innovation to Fetzer and to Galitsky's team, which is ready-



NATHAN PERKEL

ing a European version of the software. But wineries are only the beginning. Galitsky thinks a similar tool could work for a wide range of businesses. Soon the Berkeley team will test that theory at the national level, working with the six countries of the Asia-Pacific Partnership on Clean Development and Climate. These countries want to measure the environmental footprints of their cement, aluminum, iron, and steel industries; instead of evaluating a single plant, the software would grade entire countries.

All that energy research is good for the planet, but after a while Galitsky wanted to find more immediate ways to help the world's poor. So she started hanging out with do-gooder research groups. At a Berkeley meeting of Engineers for a Sustainable World, she met Ashok Gadgil, a senior scientist at Berkeley Lab who had interests similar to hers. Together, they began to look at crises in Darfur and in Bangladesh.

The problem they identified in Darfur is simple, and gruesome. More than 1.6 million citizens of this Sudanese region have been displaced by civil war, with hundreds of thousands crammed into refugee camps. They have to eat, and to eat they have to cook, and to cook they need firewood, but they have already stripped the areas around their camps bare. Local women must wander for hours outside the relative safety of the camps to gather wood. This leaves them vulnerable, and international observers have documented an epidemic of rape by roving gangs.

Nongovernmental organizations have suggested that, along with other measures to protect women, better cooking tools could reduce the need for firewood. While there have been a ton of competing ideas—everything from clay ovens to solar cookers—and a ton of opinions about which ones work best, none of them had been tested in Darfur with any rigor. So Galitsky and Gadgil went to Darfur, partnering with aid group CHF International.

Traditionally, Sudanese women balance their cooking pots on three stones over a wood fire. But lots of heat escapes, and much of the wood simply chars and smokes. As a better option, Galitsky and Gadgil looked to a simple metal stove designed in the 1980s by the Indian nonprofit organization Development Alternatives. Galitsky held a demonstration in Darfur—kind of a cross between a lab experiment and a Ron Popeil infomercial. Before a large crowd, she set up the traditional three stones, the metal stove, and a mud stove popular with many aid groups. A handful of community leaders chopped wood and stacked it into 250-gram piles. Then Galitsky cooked three separate meals, so the women could see how much wood each stove used. "The stone fire used ten piles, the mud stove used nine, and the metal one used only four or five," she recalls.

Despite the metal stove's performance, the researchers knew it would need modifications to fit life in Darfur. So Galitsky interviewed dozens of women about their lives and their cooking duties. She determined that the stove would need a windshield, to control the gusts that whip through the camps, and stakes for stability when the women stir their assida, a sticky dough that makes up most meals. She and Gadgil also need to make sure the stove can be manufactured quickly and cheaply. But the technology shows promise. "We are very excited," says Maha Muna of the United Nations Population Fund in Sudan. "The UN. and [aid groups] have funded so many projects on fuel-efficient stoves as pilots, but CHF and Berkeley Lab are actually carrying out the analysis we need to be able to determine what should be replicated."



COURTESY OF CHRISTINA GALITSKY

Christina Galitsky on her work with refugees

On our first trip to South Darfur in November and December 2005, my mentor, Ashok Gadgil, and I had two goals: to demonstrate that the cookstoves we brought were more efficient than the refugees' traditional three-stone fires, and to collect data on the needs of Sudanese refugees, through informal surveys of 50 families in Otash Camp. The days were long, but the children's smiles and the seriousness of the situation—reinforced by the tragic stories told to us by some of the brave women we met—kept me going.

Our demonstrations were an instant success: the women were impressed by how little wood the stoves burned and by how quickly they cooked. We coöperated with the people in the camps to chop the wood, measure it, and lay it out in equal weighted piles—making the demonstrations easily transparent to the participating refugees.

Before we left for Sudan, we had little idea of what the cooking conditions were like; even some of the aid workers in Khartoum and Washington, DC, did not know things essential to the design of an appropriate stove, such as the size and shape of the pots the refugees used. But our survey brought us into the refugees' homes; we met women and children, learned a little more about their day-to-day lives, and added greatly to the literature on cooking conditions in Darfur. We have come a long way since that first trip and are now raising funds to help us finalize a design for stoves that might make their lives at least a little easier.

The Berkeley researchers plan to begin delivering test stoves to refugee families this fall; they hope to produce 300,000 by next year.

In Bangladesh the problem isn't food; it's drinking water. In the 1970s, Unicef dug wells all across the country so that Bangladeshis could stop drinking contaminated surface water. The aid group's motives were pure, but the wells were not. Most were in areas with high concentrations of arsenic—in some cases, more than 100 times the level the World Health Organization has deemed safe. "It has been called potentially the largest mass poisoning in the history of the world," Galitsky says.

Recently, the United States lowered its own limit on arsenic in drinking water by 80 percent, and states are interested in new technologies to meet the tougher standard—interested, and putting up money. Gadgil and Galitsky saw an opportunity. With a $250,000 grant from the California Energy Commission and $100,000 from the American Waterworks Association Research Foundation, they are developing a filtration system that could work both here and abroad.

Arsenic is easy to filter at a big water-treatment facility, but engineers can't scale existing technologies down enough to serve individual families, or make them cheap enough for the poor world. Gadgil had an idea. Iron particles act like arsenic magnets, bonding tightly to the arsenic for easy disposal; but a filter made of pure iron powder would be prohibitively expensive. Layering a thin coat of iron onto waste ash from coal-fired power plants, however, would offer similar arsenic-attracting surface area at a fraction of the cost.

Getting the ash and the iron to stick together turned out to be a challenge. But after a dozen failed attempts, Galitsky and Gadgil came upon the solution: washing the iron-coated ash particles with lye and letting them get good and rusty.

The result, which looks something like dark curry powder, will capture nearly all the arsenic in a beaker of contaminated water. The researchers still need to figure out how water should pass through their hybrid ash-and-iron substrate, and what real-world conditions might interfere with its performance. But they believe filters made with their new medium could be effective enough to meet stringent safety standards yet still affordable enough to sell to Bangladeshi households. With Galitsky and Gadgil's method, a family could filter a year's worth of water for less than about $2; it would cost at least $58 with today's cheapest comparable technology.

Galitsky talks about all her research with a real sense of urgency, and not just because people and the environment are suffering. For the problems she is addressing big gains are tantalizingly close, and the rewards will be great—for the poor communities this kind of science can help, and for Galitsky as well.

"I felt so helpless," she says. "And I still feel helpless. But at least now I'm doing something." TR

TRANSPORTATION

Stefan Duma, 34

Virginia Tech

Better virtual crash dummies



About 1,000 fetuses die every year in the United States when their mothers are injured in car crashes. But little was known about how automotive restraints might be improved for pregnant women until Stefan Duma created the first computer model of a pregnant abdomen. Duma, director of Virginia Tech's Center for Injury Biomechanics, has also produced important models of the human eye and thorax. And he developed a sensor-rigged football helmet that has been commercialized to help doctors understand impacts to the head.

TR: We've all seen those iconic crash-test dummies. What's wrong with them?

Duma: We've come a long way using these dummies, but they are not 100 percent humanlike. They only measure discrete locations where sensors are located. They are fairly rigid compared to a human. In a computer model, we can make them more flexible, and we can have an infinite number of sensors.

How did you create your model of a pregnant abdomen?

When my wife was pregnant, I realized there was little research in this area, so I got into it. We created the model using data from sources like studies of placenta strength and validated it by studying the results of actual crashes that involved pregnant women. With this computer model, we can now "see" inside the abdomen during the accident.

There's a notion that lap belts might harm rather than protect pregnant women. What does your model show?

We've shown that the three-point belt is far superior to just a shoulder belt. But we're hoping to help make devices to better protect pregnant women. We've been better able to show the injuries they are susceptible to. We've transferred this model so that it is commercially available, and we are working with [vehicle] manufacturers on prototype pregnant belt systems.

How do these prototypes differ from existing seat belts and air bags?

There are a lot of things you can do. You could have different attachment points, different sizes, different materials construction for seat belts, for example. And we've found that the steering wheel is a key issue. That's where a lot of the fetal deaths happen.

—David Talbot

TR35

NANOTECHNOLOGY

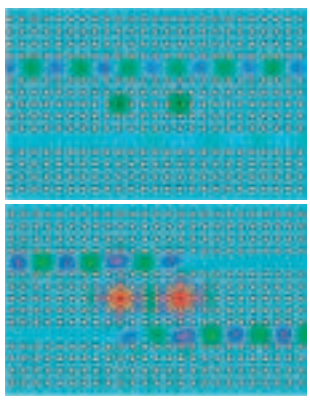
Marin Soljačić, 32

MIT

Modeling the flows of light

To understand the ambitions of Marin Soljačić, think of what the first semiconductor transistors did for the speed and power of computer circuitry—and then think photons instead of electrons.

By calculating the behavior of light in structures called photonic crystals, Soljačić is paving the way for devices



LIGHT COMPUTING **Computer models of photonic crystals allow Marin Soljačić to evaluate designs for all-optical information-processing circuits.**

that can process information at ultrafast speeds using light alone. The crystals' microscopic honeycombs shut out light of any but a few particular wavelengths; as a consequence, they could offer a way to guide data-carrying light beams within microprocessors. Soljačić has also shown how photonic crystals can enable light beams to interact and to control one another, so that photonic devices can carry out logic operations.

The all-optical computers predicted in the 1980s haven't materialized, he says, because the effects on which photonic interactions depend are usually so weak that they appear only with beams too intense to be of practical use in microchip devices. But Soljačić has shown how photonic crystals can be designed to dramatically boost these optical effects so that they will occur even with very low-power light beams.

Ultimately, he thinks, it should be possible to use a single photon to control another in a photonic-crystal device. This would reduce energy consumption and heat production enough to make optical information processing practical—and it raises the possibility of all-optical quantum computers, which would expand computer power beyond recognition.

—Philip Ball



SOFTWARE

Matthew Herren, 23

EduVision

Beaming textbooks across Africa

Growing up in Africa, Matthew Herren saw that many children in cash-strapped rural schools have to make do with textbooks that are decades out of date. Inspired to find a low-cost solution to the problem, he hit on the idea of using satellites to transmit up-to-date educational materials. He aims to establish the technology not through programs run by traditional aid organizations but through a series of self-sustaining businesses.

"We figured there had to be a way for technology to lower the cost" of providing books and other materials to children, Herren says *(see "Development Powered by Education," p. 26)*. Herren, who is Swiss, turned to one-way satellite radio transmission because Internet access is unlikely to reach much of the African interior anytime soon. In a test last year, a Swiss foundation called BioVision installed a satellite receiver in a grade school in Mbita Point, Kenya, on the shores of Lake Victoria. The receiver downloaded textbooks onto its hard drive. The information was then transferred to handheld computers rigged with simple Linux-based software for book viewing. Sixty students received current classroom materials.

Herren is now trying to implement his scheme on a grander scale. Working with Bridgeworks, a venture capital firm in Zürich, he has already raised most of the $650,000 needed for seed money. With that capital, Herren hopes to launch a network of businesses across Africa that will sell and service the satellite receivers and handheld PCs. A country's education ministry would hire one of these companies to provide and maintain its educational-download system—and slash the per-pupil cost of providing classroom materials by more than 20 percent.

If delivering educational materials by satellite works as hoped, the basic system could be used to provide remote villages with health and agricultural information. Herren notes that in many villages that lack even roads, all paths literally lead to schools. DAVID TALBOT

COURTESY OF EDUVISION (HERREN); COURTESY OF MARIN SOLJACIC

NANOTECHNOLOGY

Stéphanie Lacour, 30

University of Cambridge

Stretchable electronic skin



BOB BARKANY/GETTY IMAGES

Bioengineers who hope to help paralyzed patients by melding electronics with nerve or brain tissue face a materials challenge: living tissue and microelectronics could hardly be more different. Most tissues are supple, while the semiconductors and metals used in electronics are brittle and stiff. As a result, the implanted electronics can irritate and damage surrounding tissue. It is precisely this material difference that Stéphanie Lacour is trying to bridge.

As a postdoctoral researcher at Princeton University, Lacour fabricated thin gold strips on elastic rubber substrates that could be stretched like a rubber band without losing electrical conductivity. The Princeton group, led by electrical-engineering professor Sigurd Wagner, then used these strips as the foundation of the first stretchable integrated circuit. Connecting small, rigid islands of conventional semiconductors with the gold strips, the researchers built simple electronic devices that still worked after repeated stretchings. While these circuits consisted of just a few transistors, they demonstrated a way in which engineers might make everything from electronic "skin" for robots to extremely flexible displays.

But it's the potential applications in biology and medicine that are, Lacour says, "really thrilling." Now a research project manager at the University of Cambridge in England, she is heading an effort to create implants that surgeons could use to repair nerves severed in an injury.

At the back of her mind, says Lacour, is the goal of creating electronic skin that could cover prosthetic limbs. Eventually, the electronics could be directly connected to a person's nerves, providing mental control over the prosthetic and, through a network of sensors, "feelings" in the limb.

At the back of her mind, says Lacour, is the long-term goal of creating electronic skin that could cover prosthetic limbs.

Any application that requires an electronic interface with the nervous system could use stretchable electrodes, says Barclay Morrison, a professor of biomedical engineering at Columbia University. For example, neuroengineers are developing microelectrode arrays that neurosurgeons have begun implanting in quadriplegic patients to allow them to control computer cursors or robotic arms with their minds *(see "Implanting Hope," March 2005)*. But conventional metal electrodes are 100 million times stiffer than the brain tissue. "You're implanting really rigid needles into the brain," Morrison says. Lacour's electrodes much more closely match the elasticity of brain tissue, potentially reducing the chance of damage.

Morrison has begun using Lacour's stretchable metal electrodes in experiments to study brain injuries. The stretching of brain tissue during an accident can set off a chain of cellular events leading to the death of neurons days after the accident. Morrison is re-creating the injuries by violently stretching thin slices of brain tissue. Lacour's elastic electrodes can stretch with the tissue, recording in real time the changes in the electrical activity of the neurons.

Still, says Princeton's Wagner, the field of stretchable microelectronics is very much in its infancy. It will be at least a decade, he predicts, before the technology is ready for use in consumer products like flexible displays.

But for now, bioengineers are just happy to have a way to bridge the material gap between tissue and electronics. A material that can stretch to twice its size and still be conductive is "unheard of," Morrison says. "It's incredible." **DAVID ROTMAN**



INTERNET

Roger Dingledine, 29

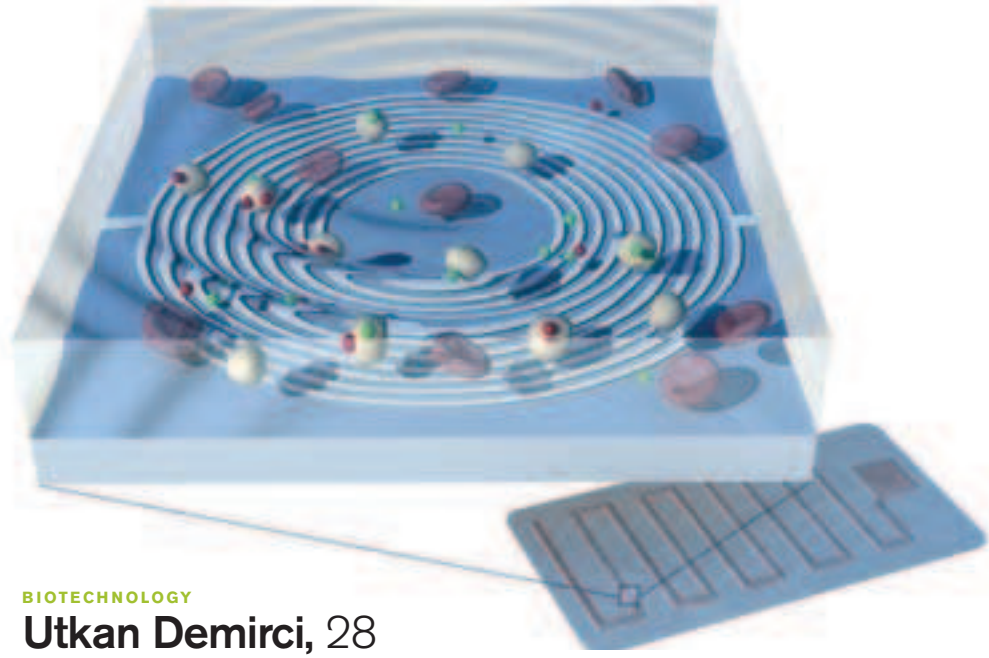
Moria Research Labs

When e-mail absolutely, positively has to get there anonymously

A dissident in China needs to e-mail a journalist in Canada. An intelligence agency wants to surveil a foreign website. Like every operation on the Internet, these activities leave tracks. "Anonymizers" provide a way around this problem; one of the most advanced is Tor, or the Onion Router.

Computer scientist Roger Dingledine developed Tor under a contract with the U.S. Naval Research Lab; today, the software is distributed by the Tor Project, affiliated with the Electronic Frontier Foundation. To disguise Internet traffic's origins, Tor plots a route through any three of more than 700 volunteer-run Onion routers around the world. It sets up a two-way link between the sender's computer and the final router in the chain; data passed between them is encrypted in three layers, and each router in the chain peels off one layer along the way. Each data packet "remembers" only the address of the last router it visited. That way, even if the data is intercepted before the final router hands it off to the recipient, it's difficult to trace back to the sender. —*Wade Roush*

MARC ROSENTHAL



AIDS ACCOUNTING
To monitor an HIV infection, a health-care worker places a drop of blood onto this disposable device. Piezoelectric rings lining the channels create sound waves that mix the blood with two labeled antibodies. Only CD4 cells bind to both, allowing specialized imaging equipment to estimate the number of CD4 cells in the sample. If it is too low, doctors know they need to initiate antiretroviral therapy.

BIOTECHNOLOGY

Utkan Demirci, 28

Harvard Medical School

Disposable AIDS diagnosis

Utkan Demirci wants doctors to take one look at his invention and "trash it." That's no knock on the device, a fast, easy-to-use—and disposable—test that measures the concentration of CD4 cells in the blood; doctors use that number to monitor HIV infections. The size of a business card, this microfluidic instrument provides an accurate cell count in less than three minutes. At less than a buck apiece, the tests, which could reach the market in a few years, could literally be a lifesaver in HIV-ridden poor countries.

Demirci developed his expertise in microfluidics as a PhD student in electrical engineering. As part of his thesis, he devised a way to print semiconductor polymers by shooting sound waves through a small reservoir of fluid, squirting out millions of droplets per second. Now an assistant professor in the Harvard-MIT Division of Health Sciences and Technology, he's adapting his printing technique to give doctors a way to grow new organs for transplant patients. Many tissue engineers build organ-shaped scaffolds, then coat them with cells, using conventional ink-jet printing techniques. Alas, the process "cooks" most of the cells. By replacing the polymers in Demirci's printer with cells, engineers can deposit one unharmed cell with each droplet. Demirci hopes to use the method to begin building his first organ next year. He's starting with one of the most challenging: the human heart. MARY CARMICHAEL



NANOTECHNOLOGY

Jeffrey Bode, 32

University of California, Santa Barbara

Peptide "Legos" to make new drugs

Problem: The market for protein-based drugs, such as insulin and human growth hormone, has doubled over the last five years, to more than $50 billion. But making therapeutic proteins is difficult. Unlike small-molecule drugs, such as aspirin, which can be synthesized chemically, proteins are typically made by genetically engineering bacteria, growing them, and extracting the final protein from them. It would be simpler if synthetic chemists could make small protein snippets called peptides from their amino-acid building blocks and then stitch them into complex proteins. But the process for making peptides is inefficient for chains more than 15 amino acids long. (Most therapeutic proteins contain anywhere from two to 30 times that many amino acids.) And existing techniques for joining peptide fragments are impractical.

Solution: Organic chemist Jeffrey Bode has come up with a more versatile way to connect peptides. Bode's group discovered that two chemical groups not normally involved in peptide synthesis react to form amide bonds, the key link between amino acids. The researchers synthesized peptides using the standard chemical recipe; they then attached one of their chemical groups to either end of each peptide. Placed in water, the peptides join together. The only by-product is carbon dioxide.

Using Bode's scheme, researchers can in theory click any two peptides together. That might eventually let drugmakers synthesize any protein from scratch. The result could be a surge in new protein-based therapeutics, many of which would contain chemical groups that are hard for bacteria to manufacture, but which would increase the drugs' stability and reduce their toxicity in the body. —*Robert Service*

BRYAN CHRISTIE DESIGN (AIDS)



CHRISTOPHER CHURCHILL

ENERGY

Michael Raab, 33

Agrivida

Making fuel ethanol more cheaply

Ethanol offers a renewable supply of auto fuel, and it can also reduce pollution. But in the United States, fuel ethanol is made almost exclusively from corn kernels, and it provides little more energy than raising, harvesting, and processing the corn consumes.

Determined to help wean the world off petroleum, bioengineer Michael Raab is putting enzymes into corn that will make it easier and cheaper to convert the entire plant—kernels, husk, stalk, and leaves—into ethanol. These proteins allow processors to break the complex carbohydrates that make up most of the corn plant into simple sugars that can be easily fermented into ethanol.

***TR*: What is your company, Agrivida, doing?**

Raab: We're taking the processing enzymes used to break down the leaves and the stalks and reëngineering them so they have no activity when they're in the plant. Then after you harvest the leaves and stalks, you can discretely activate the enzymes with a mechanism that we can control; we are using increases in temperature and acidity that coincide with normal ethanol-processing conditions.

Why is it important to design these enzymes to be inactive until needed?

Putting enzymes in plants is not a new idea, but it has not been very successful because the enzymes have a dramatic negative effect on plant development. Our engineered enzymes get around this problem by delaying their activation, which allows the plants to grow normally.

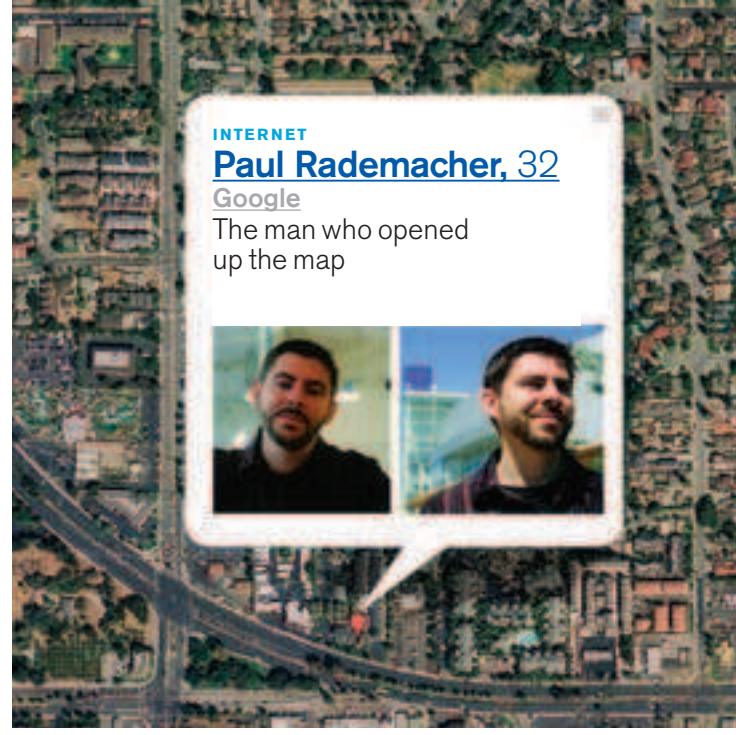
How does this process improve ethanol production?

Our enzymes allow us to more efficiently process the plant, which increases ethanol yields per acre by about 50 percent while decreasing costs per gallon by about 30 percent. In a commodity market that is growing as fast as ethanol is, that's a huge deal.

Will this process work on other plants?

We are beginning with corn; once it's proven there, we will transfer the traits into other crops, such as switchgrass, poplar, and sugarcane. That will allow geographic regions other than the Midwest to make ethanol, which decreases transportation costs; it also expands growing seasons and provides farmers with greater alternatives in their crop selection.

DAVID EWING DUNCAN



INTERNET

Paul Rademacher, 32

Google

The man who opened up the map

There's a magical moment when an unfamiliar piece of information—say, an address or an image—produces a flash of recognition, when we suddenly know where to place it. That happened to Paul Rademacher in April 2005, when he fired up his hacked version of the brand-new Google Maps site. To ease his housing hunt, Rademacher had deciphered, then modified, the JavaScript behind Google's application, creating a version that retrieved data from two different sources: Google and craigslist, the popular classified site. The result was a hybrid page that displayed Google's familiar map—and scattered across it icons indicating houses for rent around San Francisco.

Rademacher's new picture of the world—or at least of selected cities—took the Web by storm. Even Google employees wrote on a company Web page that his site, housingmaps.com, "blew our minds right off our shoulders." Thousands of people realized that Google's maps were a giant canvas on which they could doodle, taking the locations of crime scenes, favorite restaurants, or cheap gas stations and creating online tableaux for all to see. But more than that, Rademacher had shown a way to combine data and tools from completely different websites to create something new. One blogger called it a "mashup," a word DJs use to describe the mixture of vocal and instrumental tracks from different songs, and the term stuck.

For Rademacher, there's a moral to the story. Innovation is possible only when companies let you tinker with their creations. Too many good ideas are squandered, he says, because the tools needed to realize them are locked away: "To this day, there are very few technologies that are open." Creating open technologies is Rademacher's new passion. In September 2005, he left his job developing animation tools at PDI/Dreamworks Animation to pursue that passion at Google. His projects there, he says, are still "under wraps." DANIEL CHARLES

TR35



HARDWARE

Anand Raghunathan, 34

NEC Laboratories America

Making mobile secure

Problem: PCs have long been under siege from malware writers and identity thieves, but as more mobile devices connect to the Internet, they too are becoming targets—which could have even worse repercussions. Viruses that infect cell phones or PDAs can spread via Bluetooth, a wireless technology commonly used to connect handheld gadgets to PCs and onboard computers in cars. The consequences could be severe if a virus hopped from a phone to a networked PC behind a corporate firewall—or to a car's navigation system, jumbling GPS information or worse.

Solution: To make mobile devices more secure, Anand Raghunathan and his team at NEC Laboratories America have given them a supplementary processor, dubbed Moses. The processor performs all of a device's security functions, such as encryption and user authentication. Using a separate security processor isolates all the system's encryption keys, which protect passwords and personal information. So if a virus did hit a device, it couldn't access the passwords needed to log in to a bank account or an office computer; its effects would be limited. In addition, because Moses is specially designed to encrypt and decrypt data efficiently, a phone using the processor requires one-fifth the time and consumes one-third the power of a traditional cell phone performing the same tasks.

The security processors will be installed in millions of cell phones over the next few years, Raghunathan says. And he predicts that other devices will benefit from Moses, too. Radio frequency identification tags, networked sensors, and MP3 players—any small gadget with a limited power supply—could use the technology. *—Kate Greene*

BIOTECHNOLOGY

Nikos Paragios, 34

École Centrale Paris

Clearer computer vision

Vision is one of biology's most complex processes. But that doesn't stop Nikos Paragios from trying to bring this marvel of flesh and blood to the world of bits and bytes. He develops software that allows computers to interpret images more accurately, which could improve everything from medical diagnosis to driving.

As a professor at the École Centrale Paris, Paragios is a long way from the world of his childhood on the tiny Aegean island of Kárpathos, where he worked summers in a family-owned coffee shop, and there wasn't a computer in sight. "But everyone said computer science is the future," he recalls, so he headed to the University of Crete to study it.

Today Paragios is a leader in computer vision. Among his many projects is the mathematical modeling of hand gestures. The idea is to develop software to translate sign language into text, easing communication between the hearing and the deaf. The models could also allow drivers to simply point at icons printed on a dashboard—gestures that would be interpreted by onboard cameras and computers—rather than twisting knobs or pressing buttons.

Paragios is best known for his contributions to medical imaging. As a research scientist at Siemens in Princeton, NJ, he created software to automatically detect and define the boundaries of anatomical structures. Applied to magnetic resonance images of the heart, for example, the software highlights complex structures such as the coronary arteries, allowing doctors to pinpoint changes that can lead to heart attacks. Siemens is now integrating Paragios's system into its MRI scanners.



BY ALIGNING an image of a patient's aorta with an "ideal" aorta, Paragios can help doctors diagnose abnormalities.

Paragios continues to work on medical imaging technologies. With physicians at Henri Mondor University Hospital outside Paris, he's developing software to diagnose muscle diseases called myopathies without painful biopsies. Paragios and his team are turning to a variation of MRI called diffusion tensor imaging, which measures the random motion of water in biological tissues *(see "10 Emerging Technologies: Diffusion Tensor Imaging," March/April 2006)*. The goal is to create algorithms that can use this motion to determine the structure and orientation of muscle fibers, thus revealing developing myopathies.

But no matter its application, Paragios's research is driven by his desire to "do something that brings great innovation and serves society." **SHEREEN EL-FEKI**

COURTESY OF NIKOS PARAGIOS



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COMPUTER SCIENCE

The Art of the Possible

Can Eric Bonabeau's Hunch Engine expand your mind?

By Wade Roush

I am a low S trapped in a high S's body.

S is for steadiness in the DISC personality-profiling system, outlined in 1928 by psychologist William Moulton Marston (also the creator of Wonder Woman). Assessing colleagues and customers according to their need for dominance, influence, steadiness, and compliance is a skill still taught in many corporations. My outwardly high S means that if you ask me whether I would like to vacation in Italy or India, I will say Italy, because I've already been there, and I know what it's like. If I were on *Deal or No Deal* with Howie Mandel, I'd choose the cash I knew I'd won over the next briefcase every time.

THE HUNCH ENGINE
Icosystem
Cambridge, MA
www.icosystem.com/hunch.htm

Yet in my secret heart I am a low S. The best things in my life have turned up by surprise. If I let my boyfriend plan our vacations, we end up in exotic places like Shanghai or Belize, and I have a great time. I love new things when I encounter them; I just can't remember that beforehand.

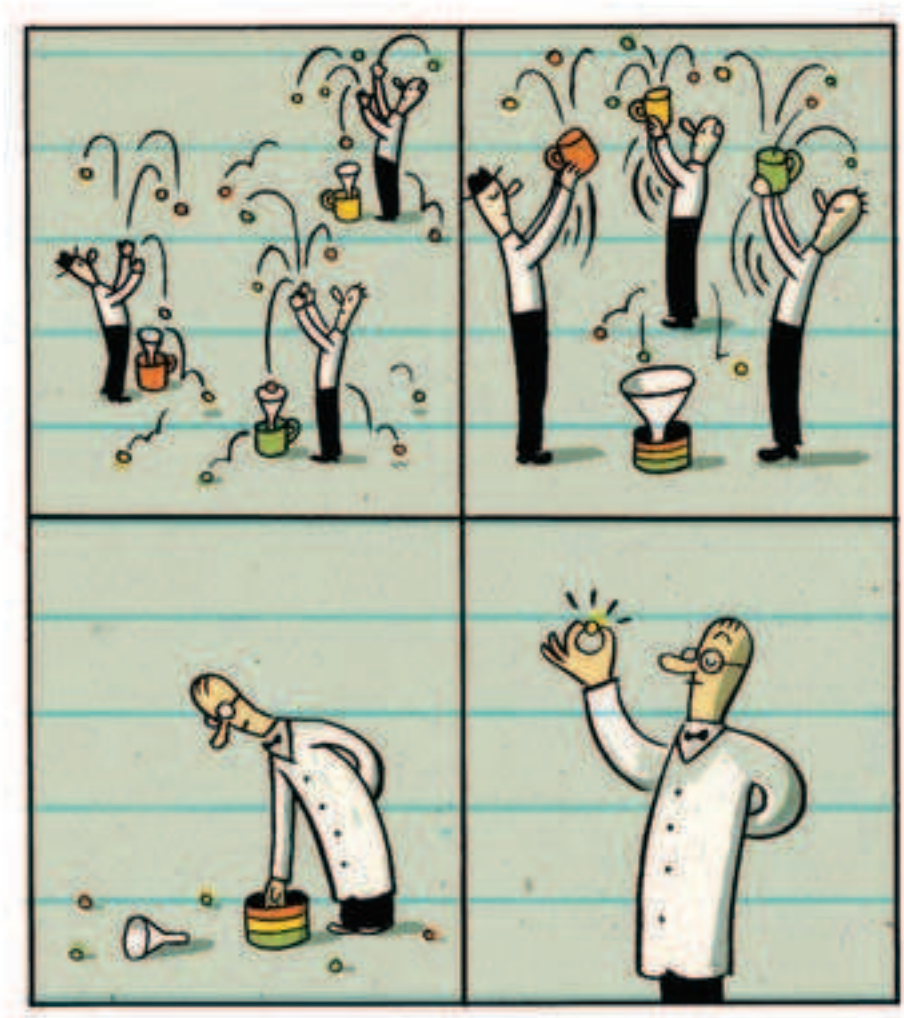
So when I heard about the Hunch Engine, my reaction was predictably dismissive. I'd been assigned to write about the design and search tool for this special TR35 issue of *Technology Review* because it had just been unveiled as the latest brainchild of theoretical physicist Eric Bonabeau, whom the magazine had named four years earlier as one of our top young innovators *(see "TR100/2002," June 2002)*. In 2000, Bonabeau had founded a company called Icosystem to commercialize his ideas about the "swarm intelligence" that emerges from systems, such as ant colonies, whose individual parts are not themselves intelligent. According to the company's publicity materials, the Hunch Engine is software that uses evolutionary algorithms to breed solutions to science, engineering, business, or design problems—solutions that no human mind could have predicted. Icosystem claims that evolutionary algorithms expose ideas to a kind of natural selection, allowing users to "reach beyond the limits of their imagination." But the notion that serendipity might produce better results than thinking and planning left me suspicious.

That was before I heard about the French letter carriers.

In June, I spent an afternoon with Bonabeau at his company's headquarters in Cambridge, MA. Bonabeau, who has degrees from Paris-Sud University, the École Polytechnique, and the École Nationale Supérieure des Télécommunications and was a research fellow at the Santa Fe Institute, is a very low S—and an almost negligible C. Over tea, we talked about the menu at El Bulli, a notoriously experimental restaurant north of Barcelona where reservations must ordinarily be made a year in advance but where Bonabeau had, the week before, won a table after a relentless series of e-mails to the maître d'. It sounded like exactly the kind of place I would never try on my own but that I in fact enjoy.

Designing efficient mail-delivery routes, Bonabeau explained to me after our tea, is an age-old headache for post-office bureaucrats. The route that's shortest in distance or fastest in time may be unfeasible for the most illogical of reasons, such as the belief among postal carriers that it's inefficient for any two mail routes to cross. Or the mailman may simply dislike his new route. A large percentage of the mail-route reorganizations attempted by post offices around the world lead to labor-management tensions and strikes, Bonabeau says.

In 2004, when the Belgian postal department turned to optimization software from the field of logistics, the result was no better. The software produced a set of routes that should have taken the department's employees 5 percent less time to complete. Unfortunately, Bonabeau says, "the mailmen hated it, and they dragged their feet," taking 30 percent longer to complete the new routes. "There are failed implementations of optimization software all over the world in postal organizations—because it's not an optimization problem at all," he says.



MARC ROSENTHAL

It is impossible, Bonabeau is saying, to design a web of postal routes around a city that perfectly fits the sensibilities of both managers and mailmen. There are only better solutions and worse solutions. It's even difficult to say what makes one solution better than the next, since "sensibilities" can't always be systematically predicted or quantified. One postal worker may prefer a longer route to a shorter one, if it goes by the patisserie where the owner greets him every day by name. One worker may prefer to walk downhill all day because of his fallen arches, while another likes a steep uphill grade because he's training for a triathlon.

No software can take all these things into account. So programmers shouldn't even try, argues Bonabeau. Instead, they should look to nature, in which random mutation and natural selection produce the features that fit an organism to its environment. Evolutionary algorithms start with a few solutions and a set of constraints, then breed generation after generation of new solutions by recombining selected elements from the previous generations *(see "Technology Design or Evolution?" July/August 2006)*. In order to steer the solutions in a certain direction, the algorithms need only be told which solutions in each generation to recombine. The choices can be made automatically, or they can be made by humans.

And that is where a program like the Hunch Engine comes in. Last year, the French postal agency La Poste hired Icosystem to spend a week combing the kinks out of the route system in a small city two hours north of Paris. On the first day, Bonabeau recounts, Icosystem handed a set of six route options to each of the city's 40 mail carriers. The carriers handed in their ranked choices the next morning, and these were fed into the Hunch Engine. The program randomly recombined the routes to generate new ones, then picked out the ones with the highest-ranked "parents." That night, the carriers ranked the new routes, and the cycle continued. After a few days of this, a persistent web of routes began to emerge; the program had homed in on a solution. And when the new routes were put into practice, the letter carriers said they were happier. Or less *malheureux*, as the case may be.

The astonishing thing, says Bonabeau, is that "the mailmen never say why they like this route or that one." Bonabeau believes that programs based on the Hunch Engine can help people with a particular class of problems: the kind where they have a hard time expressing exactly what they want, but they know a solution when they see it.

Bonabeau is careful to emphasize that evolutionary algorithms are nothing new. Computer scientists have been experimenting with them since the 1980s, and Icosystem has been selling industrial design tools based on them for several years. One tool, for example, helps pharmaceutical researchers breed biological molecules that are likely to interact favorably with receptors in the body.

What's new is the use of evolutionary algorithms in programs that laypeople might use to invent things. A simple demonstration on Icosystems' website, for instance, asks a user to select a few initial designs for Mondrianesque wallpaper or bathroom tiles; the designs' evolution can then be directed toward the pattern the user likes best. The first standalone commercial service based on the Hunch Engine will debut this fall, when Icosystems launches an online company-naming service. Bonabeau says that for $15 or so, the naming engine will let a user recombine random phonemes

and filter the resulting names until something pleasing, inoffensive, and non-trademarked emerges.

I'd been intrigued by the mailman story, but here I balked. The idea that a beautiful name might emerge from a mindless program offended me. Surely, I told Bonabeau, the quality of the solutions the Hunch Engine can generate must be limited by the quality of the real-world rules programmers are able to write into their software. These rules, I argued, must often be too numerous or subtle to capture. What kind of world would it be, I asked, if we let chance and mindless algorithms substitute for human creativity?

It was, of course, my outer high S speaking: I want to know where we're going and how we're getting there. But as usual, I was cutting myself off from exciting possibilities.

There's no need to capture all the rules, Bonabeau replied. "Your question is really about the design space," he said. "How can you make sure it's rich enough that you'll have a chance of finding something interesting? Well, there are cases where the design space is well defined. A good example is cooking, where, with five ingredients and five ways of combining them, I can already create more dishes than you can count. In those cases the Hunch Engine helps you navigate the design space. You can never be sure you're exploring the space in an exhaustive manner. But you're navigating it in a way that is a lot smarter than a random walk and a lot more empowering than being forced into a solution."

Left on my own, Bonabeau might as well have been telling me, I tend to putter in one corner of my life's design space. I am afraid to trade the route I know for the new one that's probably better. But the Hunch Engine may give us inner low Ss a taste of the wider possibilities—and a reminder that in the end, life will find its own way. TR

Wade Roush is a senior editor at Technology Review.

DESIGN

Q Is for Quixotic

Because they wanted their new Q phone to feel familiar, Motorola engineers decided it should run Windows. Big mistake.

By Simson Garfinkel

Motorola's Q phone weighs 4.1 ounces, fits easily in a shirt pocket, and is just 11.5 millimeters thick. It looks like a cross between Motorola's successful Razr flip phone and Palm's blockbuster Treo smart phone, and it's tempting to compare the Q to the Treo 700p and Research in Motion's BlackBerry 7290; all three devices are designed to let you check your e-mail, make telephone calls, save contacts in an address book, update your calendar, and browse the Web.

MOTOROLA Q
$199.99, with a two-year contract for cellular-telephone service from Verizon Wireless

But Motorola isn't positioning the Q as a Treo killer. Mike Booth, a senior director at Motorola who oversaw the product's management, told me that it isn't just another smart phone for business executives. Its relatively low price, thinness, stereo speakers, and 1.3-megapixel camera make it ideal for people who don't have high-power jobs but would like to be more organized—people like artists, college students, and stay-at-home parents.

Most cell phones now have calendars and address books built in, but they also have interfaces that must have been designed by engineers who majored in torture—"Death by a thousand clicks!" In contrast, the Q's Qwerty keyboard, jog dial, and five-way cursor control make its advanced features relatively straightforward to use—especially text messaging and the built-in Web browser.

The Q started as a project to make a stylish smart phone: think of an ultra-thin Razr with a Qwerty keyboard. Motorola wanted something that executives could use for both voice and data during the week and then take home for weekends with their families. But after trials that involved hundreds of people inside Motorola—many of whom were not technologists but receptionists, drivers, factory workers, and so on—the company realized that it had created something else altogether: an intelligent device that, says Booth, could be used by the "technologically illiterate."

For just this reason, explains Booth, Motorola decided that the Q should run the Windows Mobile 5 operating system. After all, what could possibly be more familiar than Windows?

I disagree with that reasoning. In my tests I found Windows Mobile 5 on the Q to be slow, buggy, and cumbersome. Worst of all, the phone's software generally fails to take into account the user's current activities and goals—what you might think of as the "context." Instead, Windows Mobile forces the user to understand what's going on inside the phone—how data and functionality are divided among the phone's various applications, how menus are structured, and even where files are stored.

In other words, the Q succeeds in bringing the experience of Windows to the mobile phone. This is its failing.

Hardware par Excellence

Despite its diminutive size and light weight, the Q is loaded with a combination of sweet components that isn't found in any other phone today. There's a jog wheel for fast scrolling through e-mail messages and Web pages—I wish my Treo had one! The stereo speakers are loud and have great fidelity. The camera, with a maximum

resolution of 1,280 by 1,024 pixels, takes remarkably good pictures when the light is bright. It also has a bright white LED for taking photographs in low light. Once you've taken a photo, you can send it off via Bluetooth or infrared, e-mail it to somebody as an attachment, attach it to an entry in your address book, or save it on a flash memory card. When you're taking a picture, the jog wheel controls the camera's zoom.

The hardware is awesome—and underexploited by the Windows Mobile software. For example, I found that you can also use the LED illuminator as a flashlight even when you aren't taking a photo. This is so useful that you can now download a third-party program to turn on the illuminator at the press of a button.



I've owned more than a dozen PDAs and smart phones since I bought my first Palm back in the mid-1990s, and every one of them—including all my Treos—has required a special dock or proprietary cable for synching and charging. Not so with the Q: it has a socket for a standard "mini USB" cable that charges and syncs. And the Q's headphone jack is on top—so you can use headphones with the Q in your pocket.

I have only two complaints about the Q's hardware: the screen and the phone's internal charger. The Q's screen is strictly for inside use. Indoors, the color is saturated, and the text is easy to read. But go into the sunlight and it's nearly impossible. Other phones, like my Sharp GX15, have a more expensive screen that becomes reflective in direct sunlight, which improves legibility. Worse, the Q's screen is not a touch screen: Motorola's designers told me they didn't want the extra thickness and didn't want a cell phone that required a stylus. Alas, while a touch screen might have required an extra millimeter or two, it would have made the phone much easier to use. And besides, a good touch screen doesn't require a stylus: I do most of the clicking on my Treo with my finger.

The second design flaw is that the phone won't charge from a computer USB port if the battery is drained; from a cold start, you must use the charger that Motorola provides.

Icky Software

Despite all the jazzy hardware, it's frustrating, not fun, to use the Q. This is a phone that should fit into the life of the user and the context of use, rather than forcing the user to understand its internal organization. Yet that kind of understanding is precisely what the Q demands. Geeks might gravitate to the Q for the challenge of figuring out how it works, but most average users will be exasperated.

Just consider the steps you need to go through to take an MP3 from your desktop computer and play it through the Q's stereo sound system:

First you need to set up your desktop by installing Microsoft's ActiveSync. This should be a one-click maneuver, but it's complicated because ActiveSync also wants you to configure calendar and e-mail synchronization settings. If you use Microsoft Outlook, those settings are automatically imported. But if you use Microsoft's free Outlook Express, ActiveSync recommends that you switch to Outlook! Once ActiveSync is installed, you need to reboot.

When ActiveSync is installed, a new "Mobile Device" icon will appear in your desktop's "My Computer" window. I loaded my MP3s onto the Q by dragging the files onto this icon. Each MP3 needs to be resampled at 160 kilobits per second, a process that can be excruciatingly slow. While the songs are being resampled, Windows Explorer is frozen.

Once the MP3 is on the phone, you still can't play it, because Microsoft's Media Player doesn't know it's there. After all, Media Player is a separate application. So you need to follow these steps. First, run Media Player from the phone's "Start" menu. Then click on the Q's "Menu" button. Select "Library," click "Menu" again, and select "Update Library." This makes Media Player search through all the files on the Q, looking for new music. The phone tells you how many songs it found; you click "Done" to acknowledge its report, after which Media Player displays the "Library" screen again. But this screen doesn't actually show you your music. Instead, it allows you to select "My Music," "My Videos," "My TV," or "My Playlists." Choose "My Music," and you have a choice of viewing "All Music" or music grouped by "Artist," "Album," or "Genre." Select "All Music," and you will finally see the MP3 files that you transferred from your desktop. Select a song using the arrows, and then press the left button below the screen, which is now labeled "Play."

This whole process is very logical. But I think that most people would rather just select their favorite songs, click a button that says "Put on My Q," and have all these steps happen automatically in the background. To play music, most people would like to click a button and see a list of their songs; somebody who would rather see the list sorted by artist or album could click on another button to display some kind of menu.

Using the Q is so complicated because of Windows Mobile. All these convolutions result from Microsoft's belief that the user should have lots of options and be made constantly aware of what is happening inside his or her computer.

COURTESY OF MOTOROLA

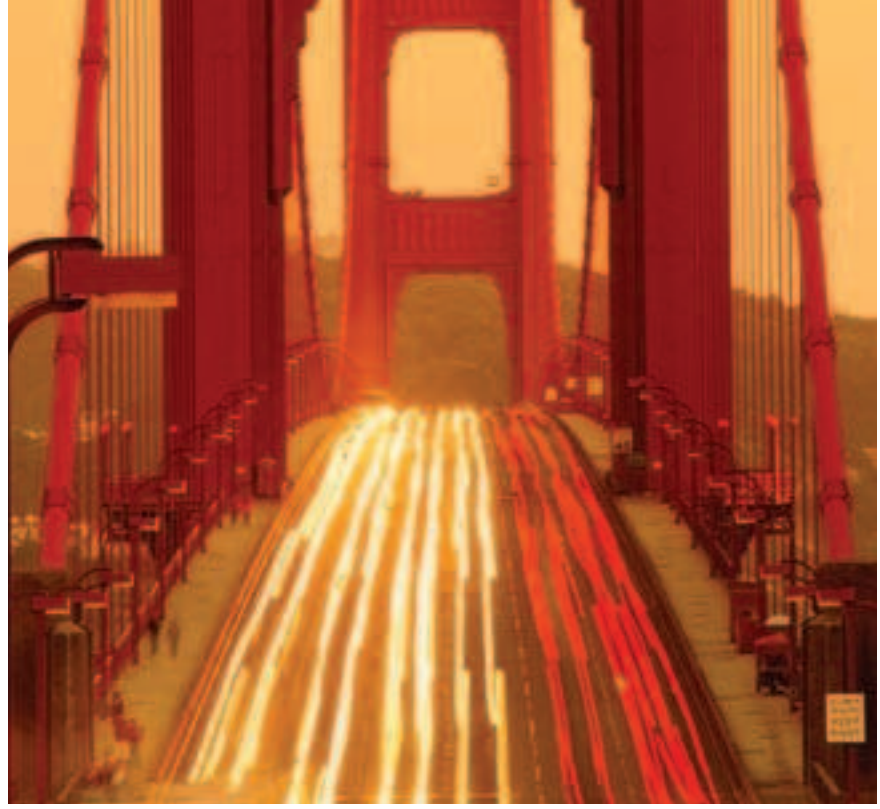
It's like driving a car with a manual transmission: control at the expense of convenience. Copy a new file onto the Q and you frequently need to click "Menu/Refresh" in the Windows File Manager to make the file appear. Try to send a message, and you'll need to select whether you want to use SMS (the Short Message Service for sending text messages between cell phones), Outlook e-mail, mail from other e-mail providers, or MMS (for sending multimedia messages between cell phones). But a single program with multiple drill-down menus doesn't reflect the way people use these different services. My Treo has one program for SMS, which works great for chat with a lot of quick back-and-forths, and a completely different application for e-mail. Each application is geared to the context in which a user is likely to use it.

It's possible to build software that tries to understand the user's context and act accordingly. Apple's iTunes, for instance, copies music to your iPod in the background and lets you set up playlists even when your iPod is not connected. The software doesn't have many options, but it's an elegant, context-aware interface.

A final way in which the Q duplicates the Windows experience is with cryptic error messages and frequent crashes. I tried to listen to my local public-radio station's Windows Media stream and got the message "Alert: An unknown error 0X80070057 has occurred." When I was evaluating the Q, I got many messages telling me that a program called gwes.exe had crashed. "Please tell Microsoft about this problem," the phone requested.

Mike Booth was right: my 10-plus years of experience with Microsoft Windows on the desktop gave me the insight I needed to diagnose and repair the recurring problem with gwes.exe. I rebooted. TR

Simson Garfinkel researches computer forensics at the Harvard Center for Research on Computation and Society.



PUBLIC WORKS

Golden Gate Lark

Should San Franciscans trust Google and their mayor to improvise the city's Wi-Fi network? **By Mark Williams**

Alongside freedom of religion and protection against cruel and unusual punishment, Internet access through a municipal Wi-Fi network is now to be reckoned a basic human right. Or so says San Francisco mayor Gavin Newsom, who announced a free wireless-access project called TechConnect in August 2005.

The proclamation was characteristic of Newsom; he combines a proclivity for media grandstanding with a weird indifference to mundane political chores like passing legislation and brokering deals among contrary factions. Still, Newsom is hardly alone in supporting urban wireless Internet coverage: some advocates of the technology argue that it could bring disadvantaged Americans the same dramatic benefits that a $100 laptop would supposedly provide in the developing world. With local governments asserting that such networks could cut their operational costs and boost economic development, more than 300 municipal Wi-Fi projects are now proceeding in the United States, according to data compiled by CNET.

TECHCONNECT
San Francisco's municipal Wi-Fi initiative
www.sfgov.org/site/tech_connect_index.asp

Is the municipal Wi-Fi boom a real advance for America's cities or a well-intentioned boondoggle? Critics argue that current Wi-Fi technology, with its slow connection speed, will be obsolete by the time most municipal networks are completed. In Orlando, FL, and some Asian cities, meanwhile, pilot Wi-Fi networks have gone largely unused by residents. The one project universally cited as a success—Philadelphia's—was preceded by careful thinking about why communities need wireless Internet access, who would use it, and at what cost.

Whatever strategic thinking was being done by TechConnect's planners seemingly went out the window in February 2006, when Google, together with EarthLink, joined the bidding to become the supplier of San Francisco's

ANDREW SHENNAN/TAXI/GETTY IMAGES

network. Newsom had been cultivating connections with the search company since January 2005, when he was reported to have hitched a ride home from the annual World Economic Forum meeting in Davos, Switzerland, aboard a jet chartered by Google cofounders Larry Page and Sergey Brin. (He later reimbursed the company for the cost of a commercial flight.)

San Francisco's specs for the network were forbidding. The city's request for proposals insisted that the network function seamlessly for users traveling at 30 miles per hour, a trick Wi-Fi engineers haven't quite perfected. The city also called for 95 percent outdoor and 90 percent indoor coverage citywide, which would require an unusually large number of Wi-Fi access points in any city, let alone one as hilly as San Francisco.

In their proposal, Google and EarthLink strove to meet these expectations. Google would foot the bill for free Wi-Fi service, which would run—or crawl—at 300 kilobits per second, about five times the speed of a dial-up modem connection. EarthLink would build the network hardware and offer, for $20 a month, a megabit-per-second service with customer support. The proposed network would require at least seven Wi-Fi access points per square kilometer, mounted on city property such as light poles and traffic lights. At this density, the network would meet the city's coverage goal but would not be guaranteed to reach above the second floor of buildings. In April, San Francisco provisionally accepted the Google-EarthLink proposal, pending successful contract negotiations.

In May, however, when I sat through a LAFCO meeting (California's Local Agency Formation Commissions handle county contractual service agreements like the proposed Google-EarthLink Wi-Fi deal) at San Francisco City Hall, I got the impression that city managers remain either deliberately indifferent to or clueless about fundamental aspects of the Google-EarthLink proposal. Of the three commission members present, one remained silent throughout. A second—Tom Ammiano, a former stand-up comic who once ran for mayor—admitted that he was still using dial-up. Otherwise, the meeting was uninterruptedly run by Chairperson Ross Mirkarimi.

Mirkarimi, a Green Party member sporting a modish soul patch and representing District 5, which includes Haight-Ashbury, at least posed some of the right questions. Would users of the ad-supported Wi-Fi simply go through a Google portal page, he asked, or would they also have to suffer through pop-ups? And since Google said that its technology could "target advertisements to specific geographical locations and to user interests," what would prevent users' locations from being tracked? To such questions, the response from the bureaucrats at the city's Department of Telecommunications and Information Services (DTIS), and from the private consultants they'd hired, was essentially, "Wise up and quit griping—the city is getting a great deal for free"

The DTIS officials were equally unforthcoming when asked whether it made much sense for San Francisco to effectively grant Google and EarthLink a monopoly on wireless Internet service for the proposed 10-year term of the contract, given how rapidly information technology advances. As Ralf Muehlen, director of the nonprofit Wi-Fi network SFLan, pointed out, "In 2021, 300 kilobits per second is going to seem a bit ridiculous. … it's a great solution for, like, 1996."

Philadelphia's Wi-Fi network is different. EarthLink will finance, build, and manage that network—meaning it will pay for infrastructure worth an estimated $7 to $10 million—and then share revenues with the city's Wireless Philadelphia initiative, while selling bandwidth to other Internet service providers. Future network upgrades are written into the contract.

EarthLink isn't offering Philadelphia a better deal out of humanitarianism but because the city asked for one. Philadelphia conducted a detailed technical study, which included pilot projects in four different parts of the city, before issuing its request for proposals. It also convened a number of focus groups across the city's economic strata. City representatives worked with ethnic groups, neighborhoods, church groups, and large businesses to ensure that programs to reach low-income communities were in place, then hosted several neighborhood launch parties to draw attention to the network and the programs, according to Craig Settles, a wireless-technology consultant and author of *Fighting the Good Fight for Municipal Wireless* (2006). San Francisco, by contrast, has not conducted even a basic feasibility study.

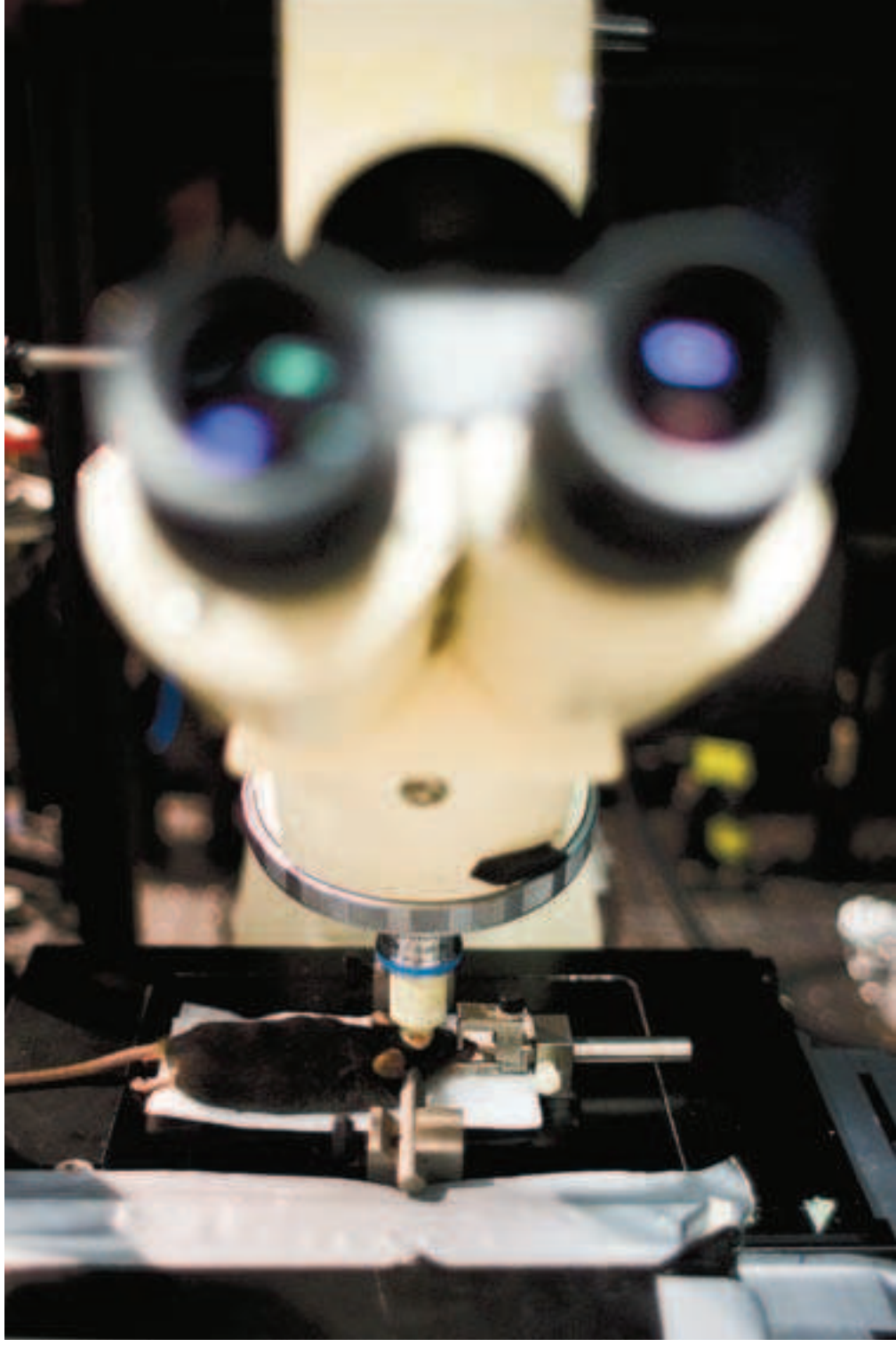
In short, Philadelphia's city government did its homework and knew what to ask for. But San Franciscans fear that Newsom will repeat his 2005 deal with Comcast, in which the city extended the company's cable franchise for four years without negotiating service improvements or lower subscription fees.

Why would it matter that Philadelphia got itself a better deal, as long as Google and EarthLink provided San Francisco with functioning municipal Wi-Fi? Because it's not a given that Wi-Fi networks pay off for cities, or even that they have many users. In January 2005, the city of Orlando pulled the plug on its free downtown Wi-Fi service because only 27 people a day were accessing it, at a cost to the city of $1,800 a month, according to the *Orlando Sentinel*. Though San Francisco's potential network might be larger, that only makes questions of design more urgent: the city could discover too late that its network was too expensive, too spotty, or already dated. TR

Mark Williams is a contributing writer at Technology Review.

Peering into the Brain

Watching live neurons in adult mice, MIT's Elly Nedivi has found a surprising amount of growth. **By Emily Singer**



In the middle of a pitch-black room, a very special mouse lies motionless on a microscope stage. Months before, the mouse had two small holes cut out of its skull, revealing the dura—the brain's outer membrane—and the blood vessels below. The holes have been permanently covered with clear glass so that scientists can peer directly into the mouse's brain, where some of its neurons glow green under the laser light of a microscope.

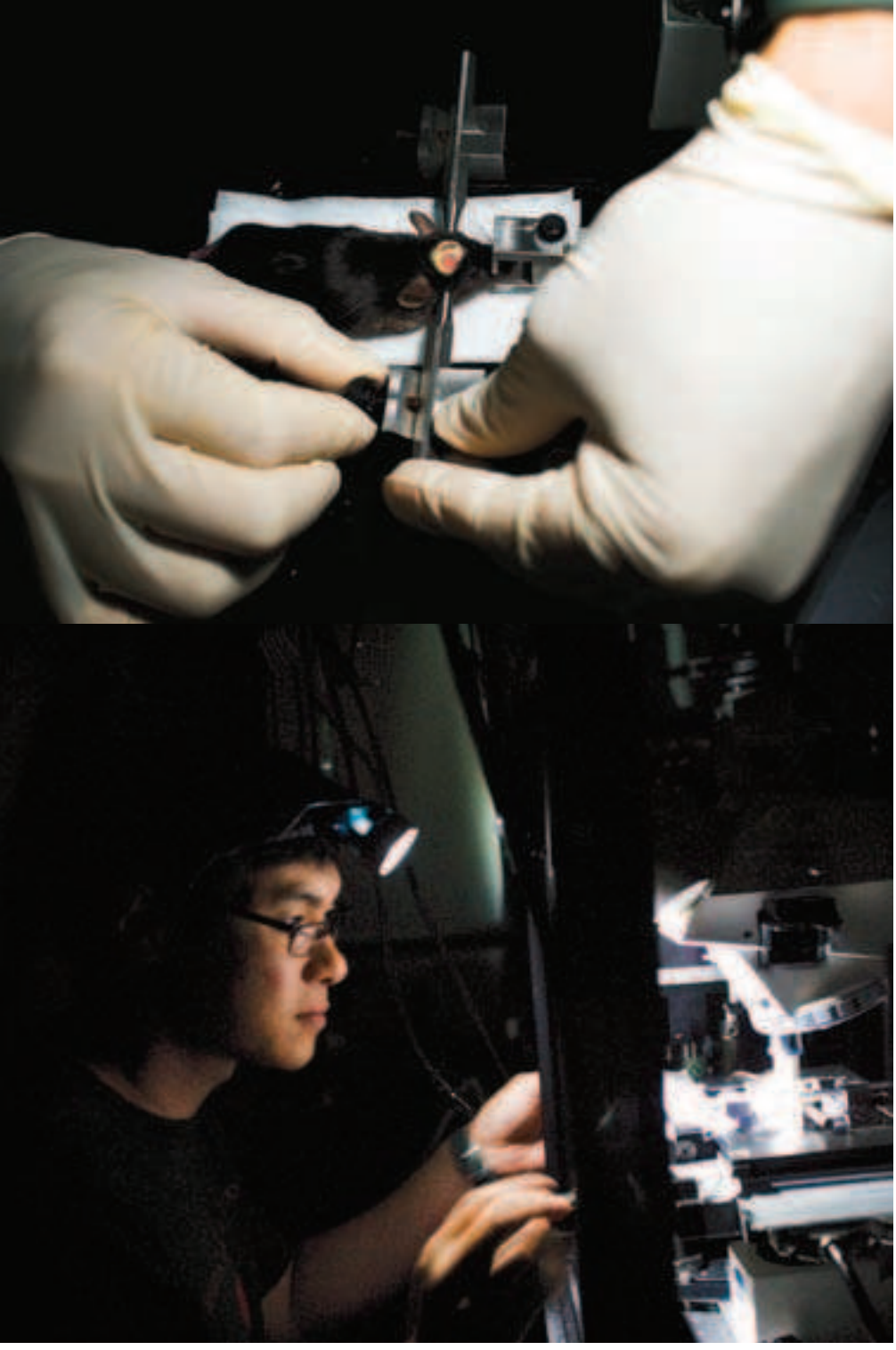
As the anesthetized mouse sleeps, Wei-Chung Lee, a postdoc at MIT's Picower Center for Learning and Memory, snaps a series of pictures of a single neuron. He will combine these photos into a 3-D image of the neuron and compare it with an image of the same cell created a week ago, to determine how it has changed over time.

The technique has given MIT scientists an unprecedented look at the surprising growth of neurons in the course of an adult mouse's everyday life. "You see the full range of types of growth you see during development, such as growth spurts, extensions, retractions, or new additions," says Elly Nedivi, the associate professor of neurobiology at MIT who heads the research. "This is what the brain is doing on a day-to-day basis." Nedivi helped develop the new imaging procedure in collaboration with Peter So, an imaging expert in MIT's bioengineering department, hoping to better explore changes in complex webs of branchlike projections that relay messages between neurons. What she has found is helping change the scientific picture of the brain.

Once upon a time, scientists thought that the adult brain was mostly static in structure—that after the neural growth spurts of infancy and adolescence, connections between neurons were permanently laid out, like a network of paved roads. But a growing body of evidence suggests that the adult brain has a surprising capacity to reorganize. Nedivi and her team have provided new support for this idea, furnishing the first proof in living animals that neurons' information-exchanging projections can grow and retract in adulthood, in ways that are qualitatively similar to what they do early in life.

Neuroscientists knew that some neural changes must take place in the adult brain, because we continue to learn throughout life. "But people didn't know if that plasticity was accompanied by structural changes," says David Kleinfeld, a neuroscientist at the University of California, San

PHOTOGRAPHS BY PORTER GIFFORD



MIT scientists use two-photon microscopy to study how adult neurons in the living brain grow and change (opposite page). Postdoc Wei-Chung Lee prepares to train the microscope on an anesthetized mouse with two windows in its skull (left).

Diego. Nedivi and her collaborators, he says, have shown that neurons of at least one particular type "continue to grow and evolve in the adult mouse."

The key to Nedivi's discovery was the ability to look at the same neuron in a living animal week after week. Most previous research on neuroplasticity—the brain's ability to form new neural connections—examined brain slices, sections of brain that are kept alive for a short time. Although such in vitro studies allow scientists to test how neural connections are affected by specific factors, such as jolts of electricity or different types of drugs, they can't show what happens to neurons in the living brain as an animal grows old, or develops a disease, or is raised in isolation.

Looking at the same cell for a period of weeks can reveal the slow growth of neurons in the brain. Nedivi hopes to use the process to determine what goes awry in the brains of mice engineered to model Alzheimer's and schizophrenia. Such studies will offer both new information about the human diseases and a way to test novel therapies.

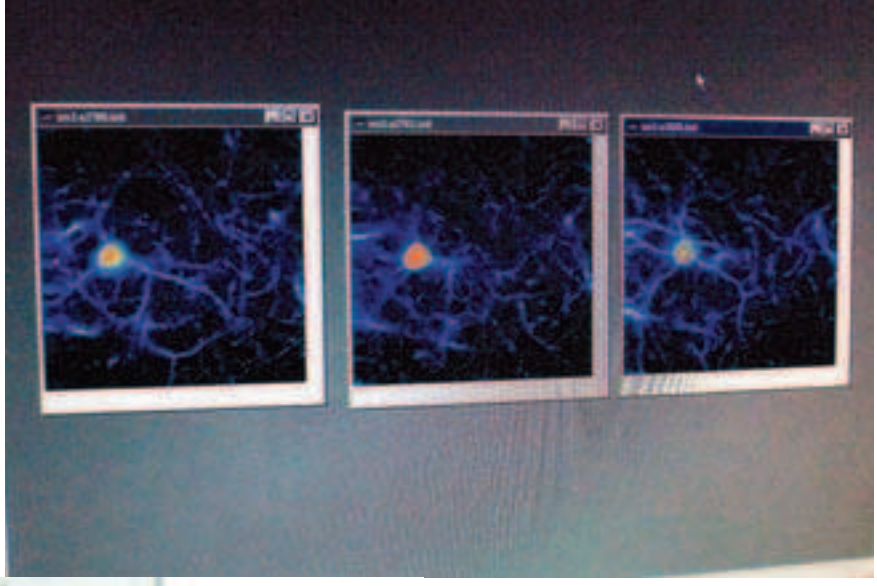
The researchers also hope to determine the best ways to encourage brain cells to grow. If neurons could be coaxed to grow new projections in specific parts of the brain or spinal cord, they might be able to compensate for the damage caused by spinal-cord injury or stroke.

A Blossoming Tree

To watch neurons in the living brain, Nedivi and her collaborators put windows in the skulls of mice genetically engineered to produce a fluorescent dye in a few randomly selected brain cells. Through the windows, they take pictures of the fluorescent neurons using a two-photon microscope, an instrument that creates very high-resolution images.

An ultrafast titanium-sapphire laser sends packets of light through a complex series of lenses and mirrors, which directs the light onto individual cells in the brain of the anesthetized mouse. The fluorescent dye in the selected neurons glows only if two photons hit a dye molecule at exactly the same time, allowing for more precise imaging of the cells. (This is why the room must be pitch black: any extraneous light would be picked up by the microscope's photon detector, muddying the resulting image. Researchers wear head lamps in case they need to adjust equipment.)

Neurons consist of a central cell body and a series of branching projections that extend into different parts of the brain to send and receive electrical signals. To capture the entire structure of a given neuron, the laser scans





Elly Nedivi and Lee (bottom) look at images of a neuron (top) generated by the two-photon microscope. They must identify the cell body and the neural projections in each image. A computer program then combines the 2-D snapshots to create a 3-D model of the neuron.

it in horizontal cross sections, plunging deeper into the brain with each sweep. Researchers go through the images—which resemble Jackson Pollock paintings—and select the shapes that correspond to the projections. A computer program then stitches the images together to create a 3-D model.

To record how the neurons change over time, the MIT researchers take pictures of the same neuron every week for several weeks, using nearby blood vessels to help locate it. In a paper published earlier this year in *Public Library of Science Biology*, the team showed that dendrites—the projections that neurons use to receive information from other brain cells—could grow and twist and bend, sending out new shoots like a blossoming tree. "It's very powerful—you can actually see the changes," says Lee. And because the images are collected from a living animal, he says, they capture the brain's behavior much more accurately than images of a brain slice, in which many of the neural connections are severed.

This type of growth had never been seen before in studies of living animals. Previous studies using two-photon imaging found small structural changes in dendritic spines, tiny bumps on the surfaces of dendrites. But these studies reconstructed only small sections of each neuron. By modeling entire cells, Nedivi and colleagues were able to see larger-scale changes that may previously have gone unnoticed. "What is most exciting about their work is that it shows an unanticipated amount of dynamism in neurons," says Josh Sanes, a Harvard University neuroscientist whose lab engineered the mice used in the study.

In addition, Nedivi's team found that only a certain type of neuron undergoes these changes. Previous studies focused on excitatory neurons, which send electrical signals that cause other neurons to fire. Inhibitory neurons, on the other hand, release chemicals that stop other neurons from firing. It is these neurons that can extend and retract new projections. Inhibitory neurons are less prevalent in the brain than their excitatory cousins and are less well studied.

Growth Factors

Nedivi's first experiments focused on mice living a standard lab life, but now that she and her team have defined the normal amount of adult neural plasticity, they can examine how different environmental or genetic factors affect the growth of the brain. Previous research, for example, showed that giving young rodents toys or raising them in a varied landscape spurs the birth of new brain cells. Two-photon imaging will allow researchers to explore how living in a complex environment influences the neural organization of the brain. Lee has recently started studying how visual deprivation affects neural plasticity in the visual cortex. These projects will help researchers figure out whether different environments make the animals' neurons grow more rapidly or rearrange more frequently, and whether those changes eventually lead to differences in behavior.

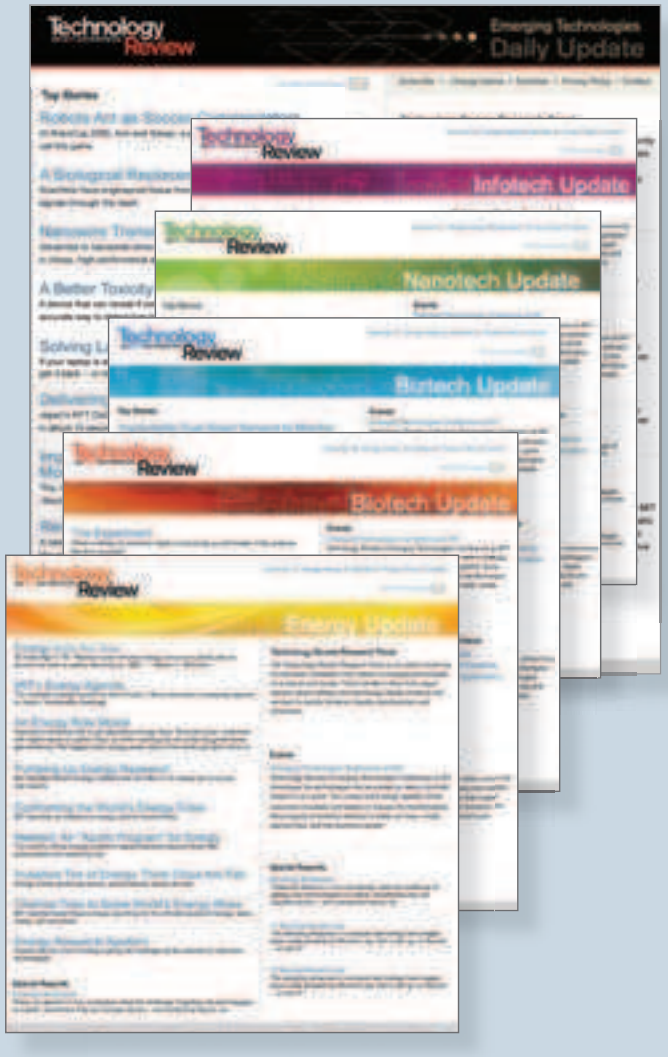
Meanwhile, Nedivi says, she has been flooded with requests from scientists studying diseases such as Alzheimer's and schizophrenia. "Once we characterize the problem with each different disease—maybe fewer projections are growing or only a certain kind of neuron is affected—then we can tailor treatments to that problem," she says. "We could also use this technology as a platform to screen for therapies."

Of course, each experiment will require months at the microscope. It takes hours to image each neuron, and days to construct a three-dimensional model from the two-dimensional images. In addition, scientists will need to meticulously compare neurons from many animals to get a sense of the differences between the behavior of diseased cells and that of healthy ones. Unfortunately, time is something Nedivi currently does not have; the lab uses a customized microscope in So's lab. Once a week, her students box up their mice and take them to the lab, imaging as many neurons as time allows. Soon Nedivi hopes to get the $500,000 necessary to set up an instrument in her own lab, which would give her researchers unlimited time to watch the brain in action. TR

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DAILY UPDATE

Emerging Technologies (Monday through Friday)

Daily insights from the authority on emerging technologies delivered straight to your inbox.

WEEKLY UPDATES

Energy (Monday) NEW!

From solar technology and biofuels to more efficient ways of burning fossil fuels and building safer nuclear power plants, we bring you the most promising energy technologies many of them ready now.

Biotech (Tuesday)

From giving mobility to spinal-cord patients to detecting cancer at the molecular level, work at the frontiers of biotechnology is rapidly transforming how we diagnose, treat, and recover from diseases. Technology Review brings you the biomedical advances that are changing our world.

Biztech (Wednesday)

New technologies are the most important source of new wealth and opportunity. Our weekly Biztech Update explores the companies and markets that are shaping the global economy.

Nanotech (Thursday)

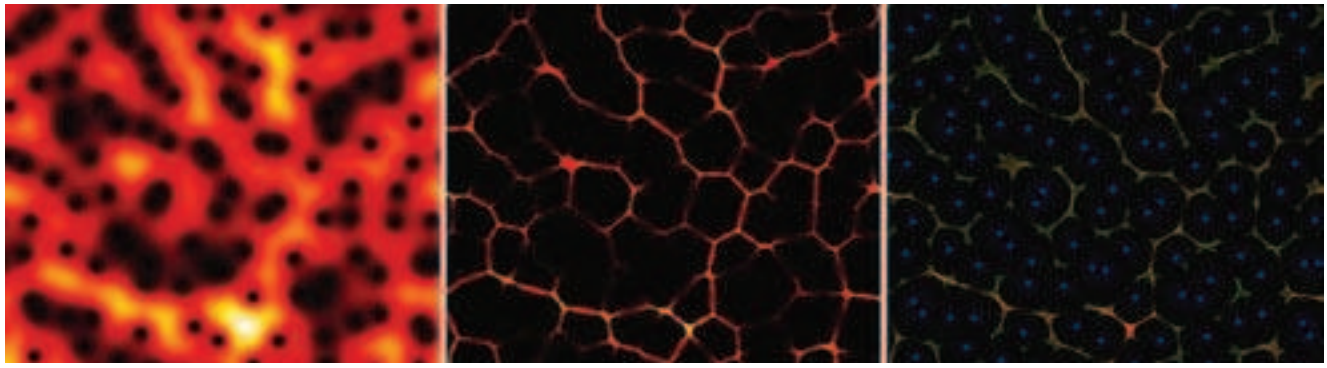
Tiny solar cells cheaply integrated into building materials. Ultrasmall electronic memory that stores vast amounts of data. Diagnostic devices able to detect single viruses. Read about the very real nanotechnologies nearing commercialization.

Infotech (Friday)

What will life be like when your computer understands what you say? When your cell phone becomes your wallet? Technology Review keeps you at the forefront of new developments in information technology and prepares you to tackle the challenges and grab the opportunities they present.

From the Labs

Current research in information technology, nanotechnology, and biotechnology



From left to right: Traditional representation of white noise; white noise analyzed using the researchers' high-resolution method; a composite image, showing that the new approach faithfully captures the features of the traditional representation.

INFORMATION TECHNOLOGY

Ultrahigh-Resolution Signal Analysis

An obscure algorithm could lead to more precise radar and a better understanding of human hearing

SOURCE: "Sparse Time-Frequency Representations"
Timothy J. Gardner et al.
Proceedings of the National Academy of Sciences 103(16): 6094–6099

RESULTS: Timothy Gardner of MIT and Marcelo Magnasco of Rockefeller University have proved that a method of high-resolution signal analysis produces faithful representations of sounds.

WHY IT MATTERS: Signal analysis algorithms have been used for decades in speech recognition software, radar, and geological imaging. A method called "reassigned time-frequency representation" can capture sound data at a theoretically unlimited level of resolution. If used in radar, for example, it could help to measure the speed of a helicopter's blades, whereas radar using traditional methods could identify only the basic shape of the helicopter. However, no one had mathematically demonstrated that the method, for all its precision, produced faithful representations—in part because it is relatively obscure in the signal-processing field. Its fidelity proven, the method could be incorporated into radar systems and signal-processing software.

METHODS: To illustrate their proof, the researchers analyzed white noise, which is similar to the static of a radio tuned between stations. They represented the noise as a two-dimensional picture with time displayed on the horizontal axis and frequency on the vertical axis. They then compared their white-noise image with one produced using traditional methods. The traditional image was blurry, with black dots that represented the complete absence of sound. The researchers found that their algorithm faithfully represented the shape of the noise pattern, including the positions of the black dots, but at a higher resolution.

NEXT STEPS: The researchers plan to apply their understanding of reassigned time-frequency representation in an investigation of human hearing. By testing their algorithms against artificial neural networks that represent auditory nerves, they will try to create better neurological models of the way the brain makes sense of sound.

Quantum Hardware

A new ion trap could make quantum computers possible

SOURCE: "A Microfabricated Surface-Electrode Ion Trap for Scalable Quantum Information Processing"
S. Seidelin et al.
Physical Review Letters 96: 253003

RESULTS: Researchers at the National Institute of Standards and Technology have developed a new device that electromagnetically traps ions. The chiplike trap is easy to make, can be mass produced, and can hold up to 12 ions to be used for quantum computation.

WHY IT MATTERS: Quantum computers would be able to perform millions of operations simultaneously; in principle, they could break complex encryption codes or search vast databases, tasks that are prohibitively time con-

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suming with current technology. Many researchers believe that a promising way to represent "quantum bits"—the basic units of quantum computation—is to use ions, or charged atoms. The ions are held in place with electromagnetic fields produced by devices called ion traps, and computations are then executed by lasers, which manipulate the behavior of the trapped ions. But most existing ion traps have drawbacks. Those that are easy to make can manipulate ions in only one trapping zone, which limits their computational power; others that allow for more trapping zones are difficult to mass produce. The NIST trap is the first that could potentially address both problems.

METHODS: Using standard microfabrication techniques, the researchers built a trap that has a single layer of gold electrodes; other types of traps have two or three layers of electrodes, making them more difficult to mass produce. The electrodes create an electromagnetic field that isolates magnesium ions and holds them in place 40 micrometers above the trap, where they could be used to perform a computation.

NEXT STEPS: The team will continue to explore more-complex traps that hold more ions. Future traps will also have structures that allow the ions to be manipulated with lasers in order to perform logic functions, a key step toward making quantum computers.

NANOTECHNOLOGY

Nano Lube for NEMS

A new way to reduce friction could make nanomachines practical

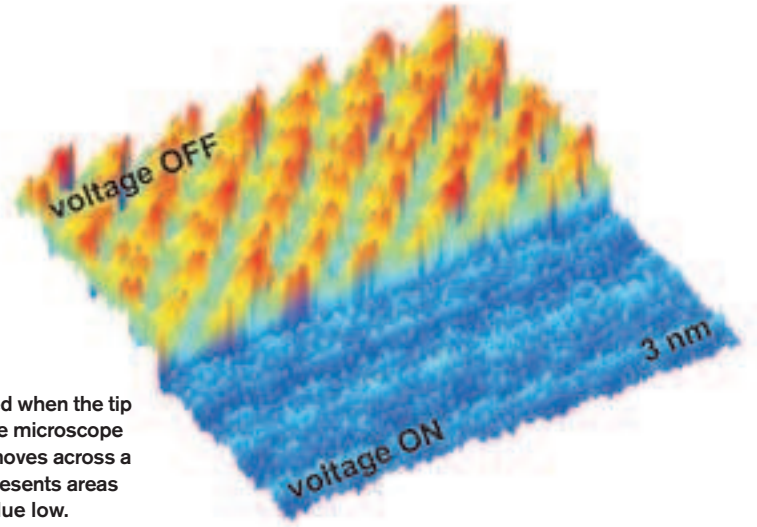
SOURCE: "Atomic-Scale Control of Friction by Actuation of Nanometer-Sized Contacts"
Anisoara Socoliuc et al.
Science 313: 207–210

RESULTS: Researchers at the University of Basel, Switzerland, have created a practical form of lubrication for nanoscale electromechanical systems (NEMS) that reduces friction between the devices' tiny moving parts 100-fold. The new method is needed because liquid lubricants do not work at the nanoscale, and other dry approaches to reducing friction have been too difficult to use in experimental nanomechanical devices.

WHY IT MATTERS: Some of the most promising nanotechnologies involve micro- and nanoelectromechanical devices, including microscopic mirrors for communications routers and ultradense computer memory that uses the tip of an atomic force microscope (AFM) to write data bits. But friction can cause the mechanical parts in these devices to wear out too quickly, limiting their commercial use.

METHODS: When researchers move a microscopic tip across a surface to make nano features, friction causes the tip to alternately stick and slip. The Swiss team eliminated this problem by vibrating the tip of a silicon AFM probe, reducing the friction between it and test surfaces of sodium chloride and potassium bromide. The application of this technique would be straightforward in AFM-based memory; other NEMS devices could incorporate small oscillators to vibrate parts that might stick.

NEXT STEPS: The researchers recently tested their method on oxidized silicon in air, and initial results suggest that it works. But they still need to apply the technique to existing devices.



Friction is reduced when the tip of an atomic force microscope is vibrated as it moves across a surface. Red represents areas of high friction, blue low.

Programmed Drug Release

Novel coatings could make safer implants, help build organs

SOURCE: "Controlling Interlayer Diffusion to Achieve Sustained, Multiagent Delivery from Layer-by-Layer Thin Films"
Kris C. Wood et al.
Proceedings of the National Academy of Sciences 103(27): 10207–10212

RESULTS: By developing a way to segregate components in ultrathin surface coatings, MIT researchers have made a new class of materials that can release drugs, and even genes, in an exact sequence and at a predetermined rate.

WHY IT MATTERS: Coated with the new materials, medical implants such as artificial hips could prove safer and more effective than their predecessors, releasing first antibiotics and then growth factors and other drugs exactly where and when they are needed. Efforts to engineer complex tissues such as bones, blood vessels, muscles, and livers could also benefit from scaffolds coated with the new materials, which could encourage the growth of specific cell types.

METHODS: The researchers dip a surface to be coated into a series of solutions alternately containing polymers of one charge and drugs or drug carriers of the opposite charge. These layered coatings will break down in water, freeing their contents. To pre-

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vent all the layers from breaking down at once, the researchers separate them with boundary layers of covalently linked molecules. The scientists believe that a given boundary layer will peel off after it has been exposed to water; but that doesn't happen until the layer above it has completely dissolved. The result is an ordered, sequential release of drugs, its timing dependent on the number of layers.

NEXT STEPS: The researchers are now developing coatings that incorporate a specific sequence of therapeutics for orthopedic applications, such as hip implants, which will then be tested for safety and efficacy.

BIOTECHNOLOGY

Growing Brain Cells

Drugs that trigger the birth of neurons could provide the next generation of treatments for neurodegenerative diseases such as Parkinson's

SOURCE: "Dopamine D_3 Receptor Agonist Delivery to a Model of Parkinson's Disease Restores the Nigrostriatal Pathway and Improves Locomotor Behavior"
J. M. Van Kampen and C. B. Eckman
Journal of Neuroscience 26(27): 7272–7280

RESULTS: Scientists at the Mayo Clinic in Jacksonville, FL, found that a drug similar to ones used to treat Parkinson's disease can spur growth of new neurons in the substantia nigra, the brain area damaged in the disease. In a study of rodents genetically engineered to model Parkinson's disease, twice as much neurogenesis, or birth of new neurons, was seen in animals treated with the drug as in control animals. Many of the newly generated cells appeared to develop into dopamine-producing neurons—the kind that are lost in Parkinson's. In addition, treated animals showed an 80 percent improvement in motor ability.

WHY IT MATTERS: Current treatments for Parkinson's disease replace or mimic dopamine, an important signaling molecule in the brain. But those treatments lose their effectiveness over time; boosting the brain's ability to make more of the dopamine-producing cells could provide a more effective strategy.

METHODS: Scientists treated rodents with a compound that triggers a dopamine receptor, delivering it directly to their brains for up to eight weeks. They then tracked the birth and development of new neurons and monitored the rodents' performance in motor tasks.

NEXT STEPS: The team is now testing drugs currently used to treat Parkinson's disease to see if they also trigger neurogenesis and, if so, how best to deliver these compounds to maximize effectiveness. Ultimately, they hope to find compounds that will help replace cells lost in a range of neurodegenerative diseases, such as Alzheimer's and Huntington's.

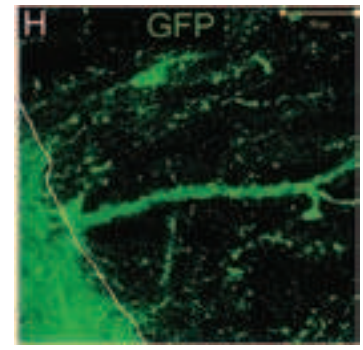
Stem Cell Mix Helps Paralyzed Rats Walk

Rodents regained mobility after receiving a combination of drugs and stem cells that rewired their nervous systems

SOURCE: "Recovery from Paralysis in Adult Rats Using Embryonic Stem Cells"
D. M. Deshpande et al.
Annals of Neurology 60(1): 32–44

RESULTS: Scientists from Johns Hopkins University found that a complex combination of treatments, including stem cells and growth factors, can heal damaged neural circuits, allowing partially paralyzed rats to walk. According to the findings, 11 out of 15 rats with spinal-cord injuries regained some motor function after receiving the full battery of treatments.

WHY IT MATTERS: Previous studies on paralyzed rats demonstrated the possibility of boosting the function of the nervous system and improving motor skills. But this is the first study to show that newly grown nerve fibers can emerge from the spinal cord, extend all the way to muscles in the rats' haunches and limbs, and form functional connections with them. These findings represent a significant step forward in regenerative medicine, providing new treatment possibilities for some types of spinal-cord injury and for diseases in which motor neurons are damaged, such as amyotrophic lateral sclerosis (ALS).



A newly grown nerve fiber extends out of the spinal cord.

METHODS: The researchers transplanted motor neurons, derived from embryonic stem cells, into the spinal cord. Then they added a mix of growth factors to help the new cells survive and grow, as well as two chemicals known to block the signals that normally keep nerve fibers from growing out of the spinal cord.

In order to get the newly sprouted fibers to span the wide gap between the spinal cord and the muscles, the researchers injected neural stem cells into the target muscles. These cells produced a nerve growth stimulator that drew growing motor neurons to the muscle and allowed them to make functional neuromuscular connections.

NEXT STEPS: The team is now planning tests in pigs. Studies in larger animals are necessary to make sure that the new neurons can grow to great enough lengths that the treatment will work in humans. If those experiments are successful, the scientists say, human clinical trials could begin within five years. TR

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Where Are They Now?

The annual selection of the TR35 got its start in 1999, with the first TR100. We do some catching up. **By Jessica B. Baker**

An Enterprising Biotechnologist

After spilling liquid nitrogen while freezing off a patient's wart, John Dobak saw a need for a self-contained



cryosurgery system that protected its chilled contents. He became an entrepreneur and based his first company, Cryogen, on this idea; soon after, he founded InnerCool Therapies, which specializes in cardiac and stroke treatments. "I try to understand where the big problems are, where there are unmet clinical needs, and then determine if there's a way to make an advancement," he says.

To help meet the needs he identifies, he cofounded the Jakk Group, an "accelerator" company that uses a broad network of resources, such as labs, engineers, and manufacturers, to advance ideas for new technologies to the proof-of-principle stage. The Jakk Group then builds a company around the concept or sells or licenses the rights to it. Current projects include a new heart catheter that employs a microelectromechanical sensor to improve patient response to cardiac resynchronization therapy. The device not only stabilizes the heart's rhythm but also reports information about cardiac contractions back to the physician. Though this is not yet at the clinical stage, the company has another therapy—for obesity—in phase I clinical trials. After going for a jog one day, Dobak noticed that the hunger he had previously felt had abated. Convinced there had to be a connection, he identified a specific nerve activated by exercise. A company that is based on this research, Leptos Biomedical, is investigating obesity treatments that electrically stimulate this nerve. Dobak says, "I'm good at the initial development, the initial creative work, and am always looking for new opportunities."

An IT Idealist

Michael Robertson has learned a lot since *TR* applauded his creation of MP3.com, a website that gave users



remote access to the music in their CD collections. The service perished in a web of lawsuits, and Robertson now recognizes his early naïveté about the complications of copyright law. But he says, "I'm proud that we helped make MP3 a global standard. You can have 20 different devices on which to listen to music. You need an open standard to do this."

His latest endeavors demonstrate his commitment to that ideal: Linspire offers an easy-to-use desktop version of the Linux operating system; SIPphone is a voice-over-IP telephone service provider that uses the most popular standard for that technology; and newly founded Ajax 13 develops Web-based applications. Robertson has even built a business, MP3tunes.com, that resembles MP3.com, which he sold to Vivendi Universal for $400 million in 2001. Reflecting on MP3.com, he says, "It was a bittersweet experience. I grew up very, very poor, so to never have to worry about money again is very sweet. However, it's bitter because I didn't get to accomplish everything I wanted to do. But it did give me the money to pursue other ideas." Those include pushing for more open formats. "I want there to be open standards," he says. "It's good for society. It prevents monopolies. It's the world I want for my two little boys."

A Conscientious Chemist

When we singled him out for his work producing plastics from carbon dioxide, Geoffrey Coates had been



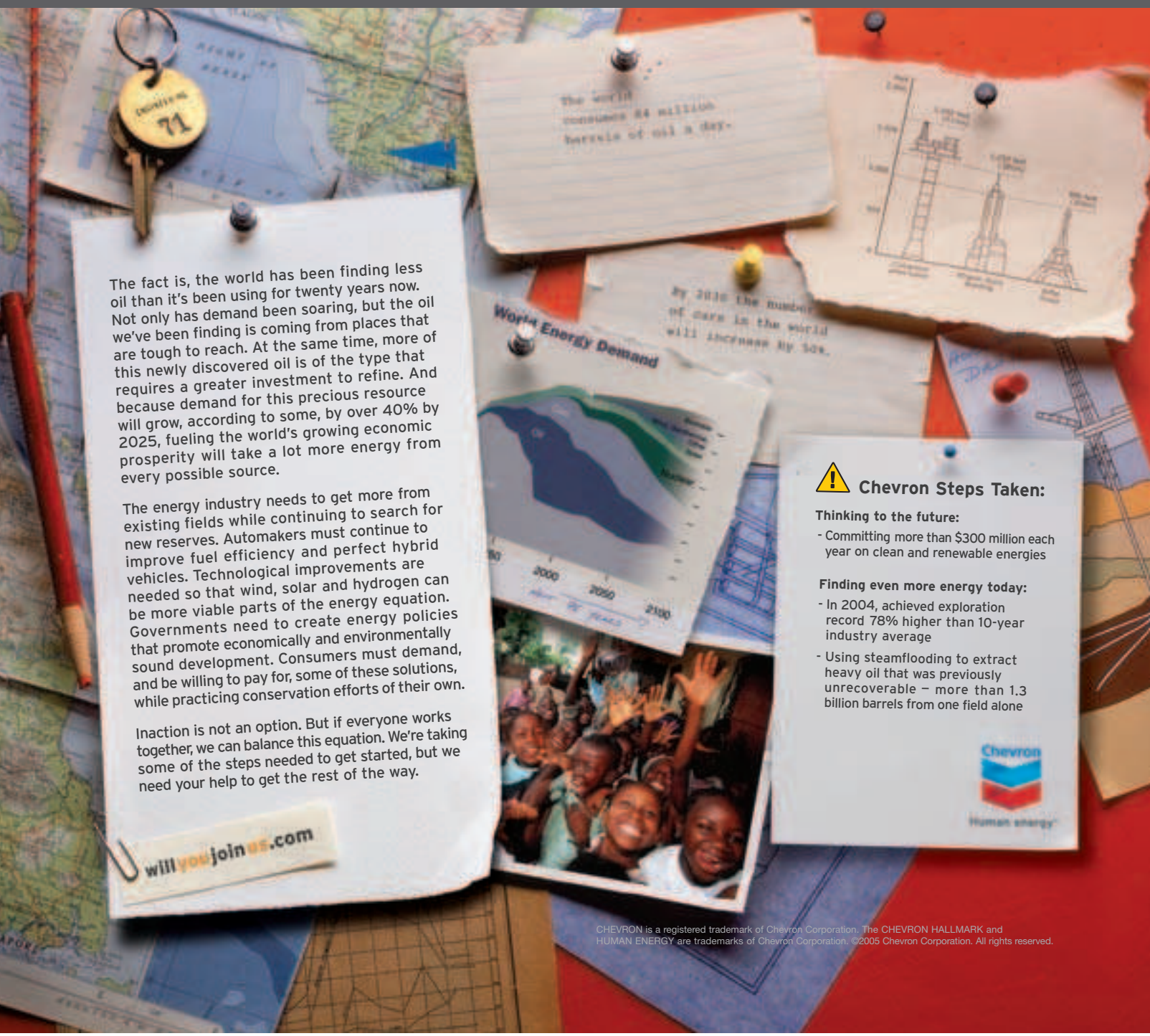
an assistant professor of chemistry at Cornell University for only two years. Since then, he has continued his quest to make biodegradable plastics from renewable resources. Because plastics, typically made from polymers derived from petroleum, play such an important and versatile part in our everyday lives, Coates says, he and his colleagues want "to move away from oil as a building block in plastics, and to make plastics that are environmentally friendly." Recently he has found success with limonene, the chemical that gives orange peels their scent. Using a catalyst, Coates combined a derivative of limonene with carbon dioxide to form a novel polymer that breaks down much more quickly than ordinary plastic. In 2004, Coates and two Cornell alumni founded Novomer, a company committed to sustainable chemistry that markets the technologies developed by Coates's research group. With press coverage from the BBC, CNN, and ABC, a special creativity award from the National Science Foundation, and an Alfred P. Sloan research fellowship, Coates, who is now associate chair of his department, has become a leader in his field. TR

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